INSTITUTION OF ENGINEERS & SHIPBUILDERS IN SCOTLAND
FOUNDED 1857 INCORPORATED 1871

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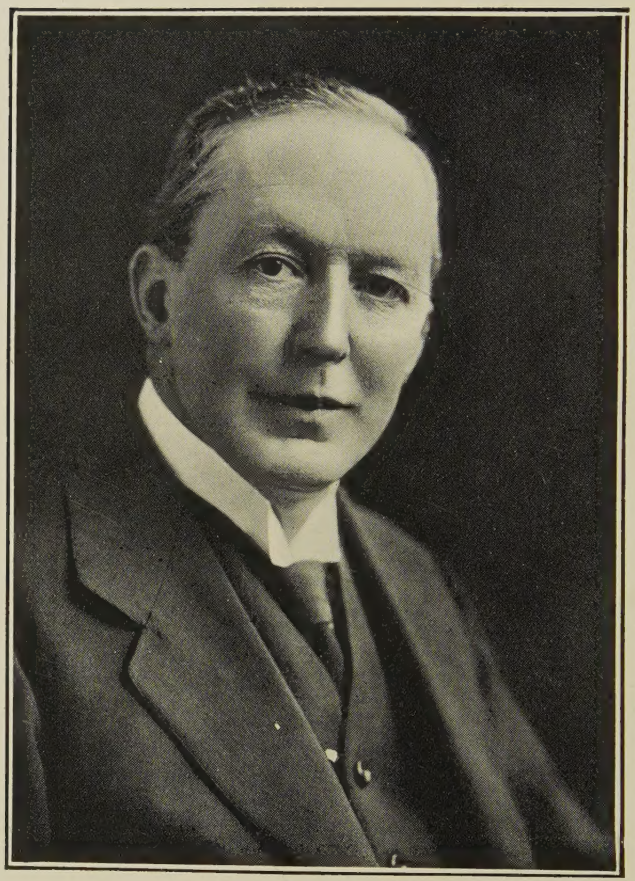

T. Blackwood Murray

TRANSACTIONS

OF THE

Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

VOLUME LXIII.

SIXTY-THIRD SESSION, 1919-1920.

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1920.

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SIXTY-THIRD SESSION, 1919-20.

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Since Foundation in 1857.

1857-59 WILLIAM JOHN MACQUORN RANKINE, C.E., LL.D., F.R.SS.L.&E., Professor of Civil Engineering and Mechanics, Glasgow University.

1859-61 WALTER MONTGOMERIE NEILSON, Hyde Park Locomotive Works, Glasgow.

1861-63 WILLIAM JOHNSTONE, C.E., Resident Engineer, Glasgow and South-Western Railway, Glasgow.

1863-65 JAMES ROBERT NAPIER, Engineer and Shipbuilder, Glasgow.

1865-67 JAMES GRAY LAWRIE, Engineer and Shipbuilder, Glasgow.

1867-69 JAMES MORRIS GALE, C.E., Engineer, Glasgow Corporation Water Works.

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1870-72 DAVID ROWAN, Marine Engineer, Glasgow.

1872-74 ROBERT DUNCAN, Shipbuilder, Port-Glasgow.

1874-76 HAZELTON ROBSON ROBSON, Marine Engineer, Glasgow.

1876-78 ROBERT BRUCE BELL, Civil Engineer, Glasgow.

1878-80 ROBERT MANSEL, Shipbuilder, Glasgow.

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1889-91 EBENEZER KEMP, Marine Engineer, Glasgow.

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1901-03 WILLIAM FOULIS, Engineer, Glasgow Corporation Gas Works.

1903-05 Sir ARCHIBALD DENNY, Bart., LL.D., Shipbuilder, Dumbarton.

1905-07 JAMES GILCHRIST, Marine Engineer, Glasgow.

1907-09 JOHN WARD, Shipbuilder, Dumbarton.

1909-10 CHARLES PULLAR HOGG, Civil Engineer, Glasgow.

1910-11 ARCHIBALD BARR, D.Sc., Professor of Civil Engineering and Mechanics, Glasgow University.

1911-13 EBENEZER HALL-BROWN, Marine Engineer, Glasgow.

1913-15 ROBERT THOMAS MOORE, D.Sc., Civil and Mining Engineer, Glasgow.

1915-17 W. W. LACKIE, Engineer and Manager, Glasgow Corporation Electricity Works.

1917-19 ALEXANDER CLEGHORN, Marine Engineer, Glasgow.

1919-20 THOMAS BLACKWOOD MURRAY, D.Sc., Automobile Engineer, Glasgow.

CONTENTS.

Office-Bearers - - - - - - - - - - - - iii
Representatives of the Institution - - - - - - - - iv
Presidents of the Institution - - - - - - - - - v
Memorandum and Articles of Association - - - - - - - ix
Presidential Address - - - - - - - - - - - 1

PAPERS READ.

Photo-Elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members—by Prof. E. G. Coker, M.A., D.Sc., F.R.S., K. C. Chakko, M.Sc., and Y. Satake, University College, London - - - - - 34
The Cruiser Stern—by P. A. Hillhouse, B.Sc. - - - - - - 95
Calculating Machines—by Dr. E. M. Horsburgh - - - - - 117
Design, Treatment, and Handling of the Snaps, etc., used in Pneumatic Hammers—by G. Denzil Hollis - - - - - - 163
The Development of Metal Construction in Aircraft—by Major J. S. Nicholson, O.B.E., R.A.F. - - - - - - - - 185
A New Type of Shipyard Crane—by W. Hök - - - - - - 266
Experiments on Riveted Joints—by Dr. James Montgomerie - - 284
High-Speed Craft During the War—by W. W. Marriner - - - 313

The "James Watt" Anniversary Dinner - - - - - - - 342
Minutes of Proceedings - - - - - - - - - - - 349
Report of the Council - - - - - - - - - - - 367
The Treasurer's Statement - - - - - - - - - - 372
Report of the Library Committee - - - - - - - - 376
Reports of Institution's Representatives on Various Boards - - 382
Report of Committee on Engineering Training - - - - - 392
Obituary - - - - - - - - - - - - - - 423
Index - - - - - - - - - - - - - - - 443

ADVERTISEMENT.

The responsibility for the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution, as a body, merely places them on record.

MEMORANDUM OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

1. The Name of the Association is "THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND."

2. The Registered Office of the Association will be situate in Scotland.

3. The Objects for which the Association is established are:—

(1) The Incorporation of the present Institution of Engineers and Shipbuilders in Scotland, under the 30th and 31st Victoria, cap. cxxxi., and

(2) To facilitate the exchange of information and ideas amongst its Members, to place on record the results of experience elicited in discussion, and to promote the advancement of science and practice in Engineering and Shipbuilding.

(3) The doing all such other lawful things as are incidental or conducive to the attainments of the above objects.

4. The Income and Property of the Association, whencesoever derived, shall be applied solely towards the promotion of the objects of the Association, as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever, by way of profit, to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them.

Provided that nothing herein shall prevent the payment in good faith of remuneration to any Officers or Servants of the Association or to any Member of the Association, or other person, in return for any services rendered to the Association.

5. The fourth paragraph of this Memorandum is a condition on which a Licence is granted by the Board of Trade to the Association, in pursuance of Section 23 of the "Companies Act, 1867." For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which may be duly observed by the Association.

6. If the Association acts in contravention of the fourth paragraph of this Memorandum, or of any such further Conditions, the liability of every Member of the Council of the Association, and also of every Member who has received any such dividend, bonus, or other profit as aforesaid, shall be unlimited.

7. Every Member of the Association undertakes to contribute to the Assets of the Association—in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the Debts and Liabilities of the Association, contracted before the time at which he ceases to be a Member, and of the Costs, Charges, and Expenses of winding up the same, and for the adjustment of the rights of the Contributaries among themselves—such amount as may be required, not exceeding Ten Pounds, or, in case of his liability becoming unlimited, such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

We, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association:—

Names, Addresses, and Description of Subscribers—

David Rowan, 217 Elliot Street, Glasgow, Engineer.
W. J. Macquorn Rankine, C.E., LL.D., etc., 59 St. Vincent St., Glasgow.
M. R. Costelloe, 26 Granville Street, Glasgow, Measuring Surveyor.
Benjamin Connor, 17 Scott Street, Garnethill, Engineer.
James Deas, 16 Robertson Street, Glasgow, Civil Engineer.
James M. Gale, 23 Miller Street, Glasgow, Civil Engineer.
W. Montgomerie Neilson, C.E., Hyde Park Locomotive Works, Glasgow.

Dated the Twelfth day of July, Eighteen Hundred and Seventy-One.

Robert Ross, of Glasgow, Solicitor, Witness to the above signatures.

NOTE.—By Special Resolution passed on 2nd October, 1902, and confirmed on 20th October, 1902, the Articles of Association dated 12th July, 1871, as modified and altered in 1873 and 1880, were annulled, and the following Articles of Association (with the exception of Articles Nos. 23, 25, and 27) were substituted, and they were registered with the Registrar of Joint-Stock Companies on 28th October, 1902.

By Special Resolution passed on 20th March, 1906, and confirmed on 17th April, 1906, the Articles Nos. 23, 25, and 27 of the Articles registered on 28th October, 1902, were cancelled, and the Articles Nos. 23, 25, and 27 below were substituted. This Resolution was lodged with the Registrar of Joint-Stock Companies on 28th April 1906.

ARTICLES OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

Section I.—PRELIMINARY.

1. For the purpose of registration, the number of Members of the Institution is declared unlimited.

2. These Articles shall be construed with reference to the provisions of the Companies Acts, 1862 to 1900; and terms used in these Articles shall be taken as having the same respective meanings as they have when used in those Acts.

3. The Objects of the Institution are those set forth in the Memorandum of Association. Objects of the Institution.

Section II.—CONSTITUTION.

4. The Institution shall consist of Members, Associate Members, Associates, Students, and Honorary Members. Constitution.

5. Candidates for admission as Members shall be persons not under 25 years of age, who have been educated as Engineers or Shipbuilders and have occupied a responsible position in connection with the Practice or Science of Engineering or Shipbuilding. Who may be Members.

6. Candidates for admission as Associate Members shall be persons not under 22 years of age, who have Who may be Associate Members.

been educated as Engineers or Shipbuilders and are engaged in the Practice or Science of Engineering or Shipbuilding.

Who may be Associates.

7. Candidates for admission as Associates shall be such persons, not included in the classes enumerated in the two preceding Articles, who, not being under 25 years of age are considered by the Council eligible on account of their scientific attainments, or are considered by the Council qualified by knowledge bearing on Engineering Science or Practice.

Who may be Students.

8. Candidates for admission as Students shall be persons not under 18 years of age who are engaged in study or employment with a view to qualifying themselves as Engineers or Shipbuilders. Before attaining the age of 25 years they must apply for election as Members or Associate Members if they desire to remain connected with the Institution. They may not continue to be Students after attaining the age of 25 years.

Who may be Hon. Members.

9. Honorary Members shall be such distinguished persons as the Council shall recommend and the Institution shall appoint. The number of Honorary Members shall not exceed Twelve.

Members, etc. under former Articles of Association

10. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Members, Associates, or Honorary Members, and whose subscriptions are not more than two years in arrear at that date, shall become Members, Associates, and Honorary Members respectively within the meaning of these Articles, and that without procedure of any kind on the part of such persons.

Graduates under former Articles of Association.

11. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Graduates, and whose subscriptions are not more than two years in arrear at that date, shall be considered and treated as Students within the meaning of these Articles,

and shall have the privileges, and be subject to the regulations affecting Students; and, notwithstanding the terms of Article 8 hereof, such Graduates as are over 25 years of age shall be allowed to remain as Students for one year from and after 30th April, 1902, but no longer.

Abbreviated Titles of Members, etc.

12. The abbreviated distinctive titles for indicating the connection with the Institution shall be the following, viz.—For Members, M.I.E.S.; for Associate Members, A.M.I.E.S.; for Associates, A.I.E.S.; for Students, S.I.E.S.; and for Honorary Members, Hon. M.I.E.S.

Candidates, how recommended and elected.

13. Every Candidate for admission as a Member, Associate Member, Associate, or Student of the Institution, shall obtain the recommendation of at least three Members, such recommendation and the relative undertaking by the Candidate being according to Form A contained in the Appendix. Such recommendation and undertaking shall be lodged with the Secretary, and the Council shall consider the same at their first meeting thereafter, and if they approve the recommendation shall be mentioned in the notice calling the next General Meeting of the Institution; and then, unless a ballot be demanded by at least five persons entitled to vote, the Candidate shall be declared elected. If a ballot be taken he shall be admitted if three-fifths of the votes are favourable; Members only being entitled to vote. The proposal for transferring any person from the Class of Students to the Classes of Associate Members or Members, or from the Class of Associate Members to the Class of Members, shall be according to Form B contained in the Appendix, and this form shall be subscribed by at least three Members and delivered to the Secretary for the consideration of the Council who shall, if they think fit, make the proposed transfer.

14. The granting of Honorary Membership to

Honorary Members, how elected.

any person may be proposed at any Council meeting, and, if the Council, after consideration at their next meeting, approve of the proposal, intimation thereof shall be given by the Secretary in the circular calling the next General Meeting of the Institution. At that meeting, unless a ballot be demanded by at least five persons entitled to vote, the person proposed shall be declared elected. If a ballot be taken then the person proposed shall be admitted if four-fifths of the votes are favourable; Members only being entitled to vote.

Members, etc., formally admitted.

15. Every person duly elected or admitted as a Member, Associate Member, Associate, Student, or Honorary Member shall be notified in writing of his election or admission by the Secretary. At the first meeting of the Institution held thereafter at which he is present, he shall be introduced according to the ensuing form, viz.—The President or the Chairman of the meeting, addressing him by name, shall say: "As President (or Chairman of this meeting) of the Institution of Engineers and Shipbuilders in Scotland, I introduce you as a Member (or Associate Member or Associate or Student or Honorary Member as the case may be)." Thereafter the new Member, Associate Member, Associate, Student, or Honorary Member shall sign the Roll of Members, etc, to be kept by the Secretary, and on making payment of any fees or subscriptions due he shall be entitled to receive a diploma. The diploma shall be signed by the President and the Secretary.

Diploma.

Rejected candidates not to be noticed in Minutes—wish of Honorary Members to be obtained before being balloted for.

16. If any person proposed for admission into the Institution be not approved by the Council, or be rejected on being balloted for, no notice shall be taken of the proposal in the Minutes of the General Meetings, and such person shall not be proposed again for admission until after the expiry of one year from the date of such disapproval or rejection. Before the meeting of Council for considering any

proposal to grant Honorary Membership, it shall be ascertained from any person proposed to be made an Honorary Member whether he will accept the honour, no notice being taken of the proposal in the Minutes unless he is elected.

Section III.—MANAGEMENT AND OFFICE-BEARERS.

Council, Management by.

17. The Direction and Management of the affairs of the Institution shall be confided to a Council, which shall consist of a President, six Vice-Presidents, and eighteen Councillors. Of the eighteen Councillors, not more than three may be Associates, the remainder being Members. Five Members of Council shall constitute a quorum.

Constitution of Council—five a quorum.

Who may be President.

18. Members only shall be eligible for election as President. The President shall preside over all meetings of the Institution and Council at which he is present, and shall regulate and keep order in the proceedings. The President shall hold office for one year only, but shall be eligible for re-election at the expiry of the year.

Who may be Vice-Presidents.

19. Members only shall be eligible for election as Vice-Presidents. In the absence of the President, the Vice-Presidents in rotation shall preside at meetings of the Council and Institution. The Vice-Presidents shall hold office for three years.

Chairman to have casting vote.

20. In case of the absence of the President and all the Vice-Presidents, the meeting may elect any one of the Council, or any Member, to preside. In all cases the Chairman of any meeting shall have a Deliberative Vote and a Casting Vote.

Who may be Councillors.

21. Members and Associates only shall be eligible for election as Ordinary Members of Council, and shall hold office for three years, and not more than three Associates shall hold office in the Council at any one time.

22. Past Presidents of the Institution shall be *ex officio* Honorary Members of Council.

First Council.

23. The Office-Bearers in office at 30th April, 1902, shall continue in office till the first General Meeting of the Institution in October, 1902, when a new Council shall be elected in terms of these Articles. Such Office-Bearers shall be eligible for election for the new Council. Of the new Council, two Vice-Presidents shall retire in October of each of the years 1903, 1904, and 1905, their places being filled by election, and the persons elected shall hold office until the expiry of the terms of office. Similarly of the new Council, six Councillors (being five Members and one Associate) shall retire in October, 1903, and a like number in October, 1904, and the remainder in October, 1905, their places being filled by election at these dates respectively, and their successors retiring at the expiry of the terms of office, and so on thereafter, from year to year. The Vice-Presidents to retire in October, 1903 and 1904, shall be determined by lot among the six Vice-Presidents first elected, and the Members of Council to retire in October, 1903 and 1904, shall be determined by lot among the Members of Council first elected. The Vice-Presidents and the Ordinary Members of Council who fall to retire at the dates mentioned, or who fall to retire at any time on the expiry of their term of office, shall not be eligible for re-election in the same capacity, nor shall a retiring Vice-President be eligible for election as a Member of Council until one year has elapsed from the date of retiral.

Retiral of Members of Council.

Office-Bearers to be elected by Ballot.

24. The Members of Council shall be elected by ballot at the Annual General Meeting, such meeting being the last Ordinary Meeting held in each month of April, but the new Office-Bearers elected at this meeting shall not enter office until 1st October following. In the election of President, Vice-Presidents, and Ordinary Members of Council from the Class of Associates, all Members, Associate Members,

and Associates shall be entitled to vote. In the election of the other Members of Council only Members and Associate Members shall be entitled to vote.

Lists for Election.

25. In March of each year the Council shall meet and prepare a list of names for the election of Council for the ensuing year. This list shall be submitted to the Members at the Monthly Meeting preceding the Annual Meeting, and the Members present may, by motion, duly seconded, propose any additional names for any of the offices.

Ballot Lists to be sent to Members.

26. Fourteen days before the General Meeting in April of each year the list as proposed by the Council for the election of Members and others to fill the vacancies in the Council for the ensuing year, with such additions as may have been made thereto under Article 25, shall be printed and sent to all Members and Associate Members, and the list shall serve as a ballot paper. A similar list shall be printed and sent to all Associates containing the names of those for whom they are entitled to vote. Those persons entitled to vote may vote for as many names on the list as there are vacancies to be filled. In the event of any ballot paper not containing names equal to the number of vacancies to be filled, such ballot paper shall be treated as a spoiled paper.

The ballot papers may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be presented personally by those entitled to vote, at the opening of the meeting.

Vacancies occurring during the Session to be filled up by the Council.

27. A vacancy occurring during any Session in consequence of the resignation or death of any Office-Bearer (except the President) shall be filled up by the Council, until the next Annual General Meeting for electing Office-Bearers. Any vacancy in the office of President shall be filled up at the next General Meeting of the Institution. A person

elected to fill a vacancy shall hold office for the period unexpired of the term of office of the Office-Bearer resigning or dying or being removed from office, and he shall not be eligible for re-election.

Section IV.—POWERS AND DUTIES OF COUNCIL.

Meetings of Council.

28. The Council shall meet as often as the business of the Institution requires, and during each Session—that is, from October till April—the Council shall meet at least once a month.

Committees.

29. The Council may delegate any of their powers to Committees consisting of such Members of the Council as they think fit, and they may appoint Committees to report to them upon special subjects. In particular, they shall appoint a Finance Committee to superintend the finances of the Institution, a Library Committee to superintend Library arrangements, and a Papers Committee to arrange for papers being submitted at meetings of the Institution. The Minutes of all Committees shall not take effect until approved by the Council. The President shall be *ex officio* a Member of all Committees.

Honorary Treasurer.

The Convener of the Finance Committee shall be styled Honorary Treasurer. He shall be elected by the Council from their number, and notwithstanding the provision for retiral in Article 23, he shall be entitled to retain the office of Honorary Treasurer for three years from the date of his appointment.

Bye-laws, etc.

30. The Council may make Bye-Laws and Regulations for carrying on the business of the Institution, and, from time to time, alter, amend, repeal, vary, or add to the same; but any Bye-Law or Regulation, or any alteration or amendment thereon, or addition thereto, shall only come into force after the same has been confirmed at a General Meeting of the Institution, and no Bye-Law or Regulation shall be made under the foregoing which would amount to

such an addition to or alteration of these Articles as would only be legally made by a Special Resolution passed and confirmed in accordance with Sections 50 and 51 of the Companies Act, 1862. The Council shall be entitled to invest the Funds of the Institution as they think fit, on such security, heritable or moveable, as to them shall seem proper, and may alter or vary the investments from time to time. The Council may purchase or sell property, heritable or moveable, for the use of the Institution, and may borrow money on the security of the property of the Institution, subject to confirmation by the Institution at an Extraordinary Meeting called for the purpose.

Investments.

Council may purchase or sell.

Borrowing.

31. The Council shall appoint a Secretary and a Treasurer, and any other official or servant required to carry on the work of the Institution, and the appointments made by the Council shall be on such terms and conditions as the Council may think fit.

Officials appointed.

32. All questions in or before the Council shall be decided by vote, and such vote shall be taken by a show of hands or by ballot; but at the desire of any four Members present the determination of any subject shall be postponed till the next meeting of Council.

Votes at Council Meetings.

Section V.—SECRETARY AND TREASURER.

33. Subject to Regulations by the Council, the Secretary (who may also act as Treasurer) shall conduct the correspondence of the Institution; attend all meetings of the Institution, of the Council, and of Commitees; take Minutes of the proceedings of such meetings, and enter them in the proper books provided for the purpose; read at all meetings of the Institution and Council respectively the Minute of the preceding meeting, and all communications received by him or ordered to be read; superintend the publication of such papers as the Council may direct; take charge of the Library; issue notices of

Duties of Secretary.

meetings; issue diplomas; keep the Roll and Registers; and perform whatever other duties are indicated in the Regulations of the Institution as appertaining to his department or set forth in the terms of his appointment.

Duties of Treasurer.

34. Subject to regulation by the Council, the duties of the Treasurer shall be to take charge of the property of the Institution (excepting books, papers, drawings, models, and specimens of materials, which shall be in charge of the Secretary); to receive all payments and subscriptions due to the Institution; to direct the collection of subscriptions; to pay into one of the Glasgow Banks, in the joint names of the President, Honorary Treasurer, and himself, the cash in his hands whenever it shall amount to Ten Pounds; to pay all sums due by the Institution, but not without an order signed by two Members of the Finance Committee, and to keep an account of all his intromissions in the General Cash Book of the Institution, which shall upon all occasions be open to inspection of the Finance Committee, and which shall be balanced annually, as at 30th September. The Treasurer shall prepare an Annual Statement of the Funds of the Institution, and of the receipts and payments of each financial year, which shall be audited by the Auditor aftermentioned, and this Statement of the Funds and an Inventory of all the property possessed by the Institution, and a List of the Members, Associate Members, Associates, and Students whose subscriptions are in arrear, shall be submitted to the First Meeting of the Council, in October.

Annual Report.

35. An Annual Report upon the affairs of the Institution shall be drawn up under the direction of the Council at a meeting to be held not less than ten days before the General Meeting of the Institution in October. This report shall embody reports from the representatives elected by the Council to various official bodies.

Section VI.—AUDIT OF ACCOUNTS.

Auditor and duties.

36. An Auditor, who must be a Chartered Accountant of at least five years standing, shall be appointed by the Council at their meeting preceding the last General Meeting of each Session, to examine the accounts and books of the Treasurer, and the Annual Financial Statement or Statements of the Funds, and that Statement, along with the Audit and Annual Report, shall be printed in the notice calling the First General Meeting of the Institution in October, and shall be read at that meeting.

Section VII.—MEETINGS AND PROCEEDINGS OF THE INSTITUTION.

Ordinary General Meetings every four weeks during the Session.

37. The Institution shall hold ordinary meetings for reading papers, and for discussing matters connected with the objects of the Institution; and such meetings shall take place regularly, at least once in every four weeks during each Session; and may be adjourned from time to time. The Sessions shall commence in October, and continue until the month of April next following, inclusive. No business shall be transacted at any meeting unless 25 Members shall be present.

At the General Meeting in April of each year for the election of Office-Bearers, the order of business shall be:—

(1) Minutes of last meeting.
(2) To read and consider the reports of the Council and Treasurer.
(3) The meeting shall nominate two Scrutineers, who shall be Members, and shall hand to them the ballot-box containing the voting papers for the new Office-Bearers.
(4) The Scrutineers shall receive all ballot papers which may have reached the Secretary, and all others which may be pre-

sented at the meeting. The Scrutineers shall then retire and verify the lists and count the votes, and shall, before the close of the meeting, report to the Chairman the names which have obtained the greatest number of votes subject to the conditions of the ballot. The Chairman shall then read the list presented by the Scrutineers, and shall declare the gentlemen named in the list to be duly elected, provided always that the list does not contain more names than there are vacancies to be filled.

Ordinary Meetings—order of business.

38. At every ordinary meeting of the Institution, the Secretary shall first read the Minutes of the preceding meeting, which, on approval, shall then be signed by the Chairman of the meeting at which the Minutes are read and approved. The Secretary shall next read any notices which may have to be brought before the meeting; after which any Candidates for admission may, if necessary, be balloted for, and any new Members shall be admitted. Any business of the Institution shall then be disposed of, after which notices of motion may be given. The paper or papers for the evening shall then be read and discussed. Each Member shall have the privilege of introducing one friend to the General Meetings, whose name must be written in the Visitors' Book, together with that of the Member introducing him; but if the introducing Member be unable to attend the meeting, he may send with the visitor a card signed by him addressed to the Secretary. During such portions of any of these meetings as may be devoted to any business connected with the management of the Institution, visitors may be requested by the Chairman to withdraw.

Nature of papers to be read.

39. All papers read at the meetings of the Institution must be connected with the Science or Practice of Engineering or Shipbuilding, and must be accepted by the Papers Committee before being read.

Proceedings to be published.

40. The papers read, and the discussions held during each Session, or such portion of them as the Council shall select, shall be printed and published forthwith.

Explanatory notes after reading of papers may be published.

41. Explanatory notes communicated after the reading or discussing of papers may be printed in the *Transactions*, if the Council see fit.

Copyright of papers shall be the property of the Institution.

42. The copyright of any paper read at a meeting of the Institution with its illustrations, shall be the exclusive property of the Institution, unless the publication thereof by the Institution is delayed beyond the commencement of the Session immediately following that during which it is read; in which case the copyright shall revert to the author of the paper. The Council shall have power, however, to make any arrangement they think proper with an author on first accepting his paper.

Members, etc. to receive copies of *Transactions*— Authors 30 copies of their papers.

43. The printed *Transactions* of each Session of the Institution shall be distributed gratuitously, as soon as ready, to those who shall have been Members, Associate Members, Associates, or Honorary Members of the Institution during such Session, and they shall be sold to the public at such prices as the Council shall fix. Authors of papers shall be entitled to thirty separate copies of their papers, with the discussions, as printed in the *Transactions*.

Special Meeting may be called by the Council or on requisition by 25 Members.

44. Extraordinary or Special Meetings may be called by the Council when they consider it proper or necessary, and must be called by them on receipt of a requisition from any 25 Members, specifying the business to be brought before such meeting.

Voting.

45. Any question which, in the opinion of the President or the Chairman of the meeting of Council and Institution, is of a personal nature shall be decided by ballot; all other questions shall be decided by a show of hands, or by any convenient system of open voting. In all cases, not hereinbefore provided for, only Members, Associate Members, and Asso-

Who may vote.

ciates shall be entitled to vote. Every Member, Associate Member, and Associate shall have one vote only, which must be given personally.

Section VIII.—SUBSCRIPTIONS OF MEMBERS AND OTHERS.

Annual Subscription payable.

46. Each Member shall, on election, pay an Entrance Fee of £1, and for the current and for each Session thereafter an Annual Subscription of £2.

Each Associate Member shall, on election, pay an Entrance Fee of £1, and for the current Session and each of the two following Sessions an Annual Subscription of £1, and thereafter an Annual Subscription of £1 10s.

Each Associate shall, on election, pay an Entrance Fee of £1, and for the current Session and each Session thereafter an Annual Subscription of £1 10s.

Each Student shall pay an Annual Subscription of Ten Shillings, but no Entrance Fee.

In the case of Members, Associate Members, Associates, and Students, elected during March and April, no subscription shall be payable for the current Session.

47. Honorary Members shall be liable for no contribution or subscription or Entrance Fee.

48. The liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payments—viz., in the case of a Member, by the payment of £25; and in the case of an Associate by the payment of £20, and, in the event of such payment being made by a Member or Associate on his admission to the Institution, the same shall be in full of Entry Money as well as future Annual Subscriptions.

49. All persons transferred, in terms of Articles 10 and 11, to the Roll of Members, Associates, or Students, to be kept under these Articles, shall not be liable to pay any Entrance Fee, but for the Session 1902-3, and thereafter, they shall be liable for the Annual Subscription applicable to the Class to which they are transferred. All persons who, as Members or Associates under the former Articles of Association, had commuted their Annual Subscrip-

tions by a capital payment to the Institution shall not be liable for any subscription, notwithstanding the terms of this Article.

When Annual Subscriptions due.

50. Annual Subscriptions shall become due on the first day of October in each year, and must be paid before 1st January following.

Members, etc., not entitled to vote if in arrear.

51. No Member or Associate Member or Associate whose subscription is in arrear shall be entitled to vote at any meeting of the Institution nor to receive copies of papers or proceedings while the subscription remains unpaid.

52. Any Member, Associate Member, Associate, or Student whose subscription is more than three months in arrear shall be notified by the Secretary. Should his subscription become six months in arrear he shall be again notified by the Secretary, and all his rights in connection with the Institution shall be suspended. Should his subscription become one year in arrear he shall be removed from the Roll of the Institution unless the Council may deem it expedient to extend the time for payment.

Members, etc retiring from the Institution.

53. Any Member, Associate Member, Associate, or Student retiring from the Institution shall continue to be liable for Annual Subscriptions until he shall have given formal notice of his retirement to the Secretary. Contributions payable by Members, Associate Members, Associates, or Students shall be debts due to the Institution, and may be recovered by the Treasurer.

Remission of Subscription in certain cases.

54. In the case of any Member or Associate who has been long distinguished in his professional career, but who, from ill health, advanced age, or other sufficient cause, does not continue to carry on a lucrative practice, the Council, if they think fit, may remit the Annual Subscription of such Member or Associate, and they may remit any arrears due by him. Any such case must be considered and reported upon to the Council by a Committee appointed by the Council for the purpose.

Council may refuse to receive subscriptions in certain cases.

55. The Council may refuse to continue to receive the subscription of any person who shall have wilfully acted in contravention of the regulations of the

Institution, or who shall, in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution, and may remove his name from the Register, and he shall thereupon cease to be a Member, Associate Member, Associate, or Student (as the case may be) of the Institution.

Section IX.—GENERAL POWERS AND PROVISIONS.

Powers of Institution in General Meeting.

56. Any Extraordinary or Special Meeting of the Institution, duly called, shall have power by a majority in number of the persons present thereat entitled to vote, from time to time, to review the decisions or determinations of the Council; to remove Members of Council; to expel Members, Associate Members, Associates, Students, or Honorary Members from the Institution, and to expunge their names from the Roll; and to delegate to the Council all such further powers as may be considered necessary for efficiently performing the business of the Institution. At any Extraordinary or Special Meeting 50 Members shall be a quorum.

To delegate powers to Council

Common Seal.

57. The Institution shall have a common seal, which will be under the charge of such of the Office-Bearers as the Council may appoint, and all instruments bearing the seal shall be countersigned as the Council shall direct.

Section X.—NOTICES.

Notices.

58. Notices requiring to be served by the Institution upon its Members, Associate Members, Associates, Students, or Honorary Life Members may be served either personally, or by leaving the same, or by sending them through the post; and notices so posted shall be deemed to have been duly served. No Members, Associate Members, Associates, Students, or Honorary Life Members who have not a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to any such.

59. Notices for any General or Extraordinary or Special Meeting of the Institution must be given by the Secretary to all Members, Associate Members, Associates, or Honorary Life Members at least four days before such meeting. Notices of any adjourned meeting shall be given at least two days before the adjourned meeting is held. Such notices shall specify the nature of the business to be transacted, and no other business shall be transacted at that meeting. Induciæ of Notices.

60. Notices for any meeting of Council must be given by the Secretary at least four days before such meeting. Notices for the meeting of Committees shall be given as the Council shall direct. Notices.

61. In computing the *induciæ* of any notice, the day on which the same is delivered shall be reckoned as an entire day. Computation of Induciæ.

APPENDIX.

Form A.

Form of Recommendation and Undertaking.

A. B.....of.....being upwards of.....

years of age, and being desirous of belonging to the Institution of Engineers and Shipbuilders in Scotland, I recommend him, from personal knowledge, as in every respect worthy of that distinction because (here specify distinctly the qualifications of the Candidate according to the spirit of Articles 5, 6, 7, and 8).

On the above grounds I beg leave to propose him to the Council as a proper person to belong to the Institution.

.....*Member.*

*Dated this.....day of.....*19

We, the undersigned, from personal knowledge, concur in the above recommendation.

.....*Member.*

.....*Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

.....

The Council having considered the above recommendation present A. B. to be balloted for as..... of the Institution of Engineers and Shipbuilders in Scotland.

Passed by the Council.....19

Balloted for.....19

.....*President (or Chairman).*

FORM **B.**

Form for Transfer from one Class to another.

A. B.....of.....having been a..... of the Institution of Engineers and Shipbuilders in Scotland for.....years, and being desirous of becoming a.....of the Institution, we, from personal knowledge, recommend him as in every respect worthy of being elected a..... of the Institution.

.....*Member.*

.....*Member.*

.....*Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

.....

The Council having considered the above recommendation and undertaking approve of the same.

.....*President (or Chairman).*

Dated this.....*day of*.....19

BYE-LAWS.

MEDALS AND PREMIUMS.

Marine and Railway Engineering Medals.

1. Each of the two Medals founded by subscription, for the best paper in the Marine and Railway Engineering Departments respectively, shall be awarded by the vote of a General Meeting, not oftener than once in each Session.

Institution Medal.

2. The Council shall have power to offer annually a Medal for the best paper on any subject not comprehended by the Marine and Railway Engineering Medals. Such additional Medal to be called the Institution Medal, and to be paid for out of the funds of the Institution, until a Special Fund be obtained. This Medal also shall be awarded by the vote of a General Meeting.

When Medals may not be awarded.

3. If it shall be the opinion of the Council that a paper of sufficient merit has not been read in a particular department during any Session, the Medal shall not be given in that department; and, in the case of theMarine and Railway Engineering Medals, the interest arising from the particular Fund shall be added to the principal.

Medals and Books may be awarded.

4. If the person to whom a Medal may be awarded shall express a wish to receive a Bronze Medal, accompanied with the extra value in books, in lieu of the ordinary Gold Medal, the award shall be made in that form. The Council may recommend premiums of books in lieu of, or in addition to, the Gold Medals. The value of such premiums of books to be determined by the Council.

MANAGEMENT OF THE LIBRARY.

Appointment of Library Committee.

5. The Council, at their first meeting each Session, shall appoint eight of their number to form a Library Committee, one of the eight to be Honorary

Librarian and Convener of the Committee. Three Members of the Committee shall form a quorum.

Secretary shall have charge of Library.

6. The Secretary of the Institution shall have charge of the Library, and shall also act as Secretary of the Library Committee.

Powers of Library Committee

7. The Library Committee, subject to the sanction of the Council, shall expend in books and Library expenses the sums placed at their disposal, and, subject to the approval of the Council, may make Bye-Laws for the management of the Library, and appoint Assistants. The sum of £30 or thereby shall be expended annually out of the funds of the Institution, in the purchase of books for the Library, in addition to the ordinary expenditure in binding, etc.

Duties of Library Committee and Annual Report.

8. The Library Committee shall annually make an examination of the property in connection with the Library, and report to the Council, detailing the state of the Library affairs.

LIBRARY BYE-LAWS AS TO USE OF BOOKS.

When Library is to be open.

9. Except during Holidays and Saturdays, the Library shall be open each lawful day from 1st May till 30th September inclusive, from 9.30 a.m. till 5 p.m. On Saturdays the Library shall be open from 9.30 a.m. till 1 p.m. On the 1st October and thereafter throughout the Winter Session the Library shall be open each lawful day from 9.30 a.m. till 8 p.m., except on meeting nights of the Institution and Royal Philosophical Society, when it shall be closed at 10 p.m. The Library shall be closed for the Summer Hoidays from the 11th July till 31st July inclusive.

Who may borrow books.

10. Books shall not be lent to any persons except Members, Associate Members, Associates, Students, or Honorary Members of the Institution; but a person entitled to borrow books may send a messenger with a signed order.

11. The books marked with an asterisk in the

Catalogue shall be kept for consultation in the Library only, and shall not be lent. Books for consultation only.

12. The Librarian and Assistant Librarian shall take their instructions from the Secretary of the Institution. They shall keep an Accession Book, in which shall be entered the particulars of all books purchased for or donated to the Library. Librarian to keep Accession Book.

13. The Librarian, or Assistant Librarian, shall keep a Register in which he shall enter the titles of the book or books lent, the date of lending, the name of the borrower, and the date of the return of the book or books to the Library. Register kept of books lent.

14. The borrower of the book or books, or, in his absence, the bearer of his order, shall sign his name to the entry of such borrowing in the Librarian's Register. Borrower to sign for books.

15. The Librarian, or Assistant Librarian, shall sign his initials to the date of the return of the book or books. Librarian to certify return of books.

16. The borrower shall be responsible for the safe return of the book, and if it be damaged or lost he shall make good such damage or loss. Should books be returned in a damaged condition, the Librarian, or Assistant Librarian, shall immediately make an entry of the fact in the Register, and report the same to the Library Committee without delay; and he shall give notice in writing of such entry, and report to the person from whom he last received the book, within three clear days of the receipt of the book, exclusive of the day of receiving the book and the day of giving such notice. Books damaged to be entered in Register. Intimation to Library Committee, and notice to last borrower.

17. No person shall be entitled to borrow, or have in his possession at one time, more than two complete works belonging to the Library, or two volumes of any periodical. Number of books which may be borrowed at one time.

18. No person being six months in arrears with his subscription to the Institution shall be at liberty to use the Library or Reading Room. Persons in arrears of Subscription not to have use of Library.

Time books may be obtained.

19. No borrower shall have the right to retain a book longer than thirteen clear days, exclusive of the days of borrowing and returning; and written notice shall be sent to the borrower one day after the time has expired. In no case shall any book be kept longer than twenty clear days.

Lots to be drawn when two may apply for the same book.

20. In the event of two or more persons applying for the same book at the same time, the applicants shall draw lots for priority.

Introduction of friends to Reading Room.

21. Each Member shall be entitled to introduce a friend to the Reading Room, whose name shall be written in the Visitors' Book, together with that of the Member introducing him.

Annual scrutiny of books.

22. All books belonging to the Library shall be called in for inspection, and the lending out of books shall be suspended in each year for one week, being the last seven clear days of March; and all Members shall be required by an intimation to be inserted in the notice calling the preceding meeting of the Institution, to return all books in their hands to the Library on or before the day next preceding the period before mentioned.

NOTE.—The Library and Reading Room are open to Members, Associate Members, Associates, and Students; and the Library of the Philosophical Society is open for consultation.

WILLIAM BROWN, *Convener.*
WILLIAM M. ALSTON.
PROF. A. BARR, D.Sc.
W. A. CHAMEN.
E. HALL-BROWN.
WILLIAM MELVILLE.
JOHN STEVEN.
JOHN WARD.
EDWARD H. PARKER, *Secretary.*

21*st April*, 1903.

INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS

IN SCOTLAND

(INCORPORATED).

PRESIDENTIAL ADDRESS

OF

Dr. T. BLACKWOOD MURRAY.

18th November, 1919.

Gentlemen,

Upon assuming the duties of President of this Institution I desire in the first place to express my thanks to the members of the Institution for the very great honour they have conferred upon me in appointing me to this high office, and to say how very deeply I appreciate that honour.

I must confess that I felt extremely diffident of accepting the invitation, knowing full well the great responsibility it entailed, and being fully conscious of the difficulty of following in the steps of the great and eminent engineers who have been my predecessors in this chair. I can only assure you that I shall endeavour to discharge the duties to the best of my ability, and to do all that in me lies to maintain the honour of the Institution and to further its interests in every direction.

On the occasion of the inaugural meeting of the past five sessions we have met under the shadow of the greatest war

which humanity has ever experienced, greatest in every sense of the word, and it is indeed with thankful and joyous hearts that we meet to open this session, after a great victory and with the nation at peace. It was admittedly, above all things, an engineer's war, and it would be difficult to overestimate the magnitude or importance of the effort made by the combined body of British engineers, and no small part of that effort was contributed by the engineers of Glasgow and the Clyde.

The war was a soul-searching trial for us, both as individuals and as a nation. No fewer than 29 members of this Institution made the supreme sacrifice, and it will ever be our duty to hold their memory in highest honour and reverence. Perhaps the saddest point about those brave men, who gave their lives for the cause of liberty and right, is that for the most part they had just entered the portals of manhood, and had in the ordinary course of nature the expectation of a long and useful life before them. In this respect the loss of such useful lives to the community is deeply to be deplored. Numbered among those who fell thus untimely were some of our most brilliant young men of science, whose work had already given sure promise of great achievements. But there is another side to the picture, those who have experienced the ordeal of battle and have been tried as by fire, have returned with a different outlook on life, and with a fuller appreciation of duty, and this moulding of character will undoubtedly have a beneficial effect on their future work.

While during the war the engineer was called upon to put forward his maximum effort, now that it is over, and over successfully, he will not be at liberty to rest on his oars. On the contrary, the work of reconstruction is of such paramount importance to the stability and the life of the nation that, in this work of reconstruction the engineer must play a leading part. It depends largely on his efforts whether this country will maintain her position as a leader of nations or not. One need not, however, view the future with any apprehension, for

hard work and plenty of it is the best prescription for a happy life; therefore, the engineer is to be envied rather than pitied, more especially as his work is always full of interest.

Of late years the tendency has been to divide the various branches of engineering into separate Institutions, each dealing exclusively or largely so with problems belonging to their own particular subjects. The outstanding exception is perhaps the Institution of Civil Engineers, which accepts papers on all branches of engineering, and another instance is that of our own Institution, which not only meets and discusses all kinds of papers on engineering subjects, but has selected for Presidents men connected with very varied sections of our profession. While not for a moment questioning the necessity or desirability of special Institutions for special branches, it is surely an advantage in a great engineering centre like Glasgow to have an Institution, such as ours, embracing as it does in its membership all kinds and denominations of engineers; for while an engineer should know all about the one branch of his profession he may have adopted, he ought to know a little about all branches of engineering, and this can be largely achieved by attending such meetings as are held here at which papers are read and discussed. Our Institution, therefore, performs a most useful and necessary function, and deserves the hearty and vigorous support of all Scottish engineers in its various activities. The advantages of such an Institution are particularly great for the young engineer who wishes to succeed in his profession. In addition to the ordinary meetings of the Institution, there are regular meetings of the Students' Section, where excellent papers are read and discussed; there are also the privileges of the reading room and reference library. The opportunity also of meeting one's fellow-students interested in other branches of engineering often forms the foundation of life-long friendships, which, in the course of years, may do much to contribute to success in life. I would, therefore, most strongly recommend the advantages of membership, particularly

to the younger members of our fraternity, and we should all remember that it is from the ranks of youth that the membership and life's blood of the Institution must ever be recruited.

During the past 25 years there has sprung into being a branch of mechanical engineering which has already become an important subdivision, namely, the manufacture of light internal combustion engines for the propulsion of motor cars, motor boats, flying machines, and such like, and as I happen to be the first President of this Institution directly connected with this branch of the profession, I feel that it is a great honour to that section that a motor car manufacturer should have been called to the chair of this Institution, and it is natural that I should wish to direct your attention this evening to some of the features of mechanical transport. In connection with the internal combustion engine there are so many points of interest to be touched upon that, in an address such as this, it is a matter of difficulty to discriminate. May I ask your indulgence, therefore, should many points of considerable importance be omitted, and plead as my excuse the vast amount of ground which is covered by the development of these engines.

The importance to mankind of improvement in every means of transport is so great that no apology is required for discussing it. As showing that this point has long been recognised not merely by engineers, but by the world at large, I cannot do better than quote the following passage written by Macaulay, the great historian, more than half a century ago:—

"The chief cause which (prior to the eighteenth century) made the fusion of the different elements of society so imperfect was the extreme difficulty which our ancestors found in passing from place to place. Of all inventions, the alphabet and the printing press alone excepted, those inventions which abridge distance have done most for the civilisation of our species. Every improvement of the means of locomotion benefits mankind morally and intellectually, as well as materially, and not only facilitates the interchange of the

various productions of nature and art, but tends to remove national and provincial antipathies, and to bind together all the branches of the great human family. In the seventeenth century the inhabitants of London were, for almost every practical purpose, further from Reading than they now are from Edinburgh, and further from Edinburgh than they now are from Vienna."

Some 35 years ago Gottlieb Daimler conceived the idea of constructing a light high-speed internal combustion engine for the purpose of propelling a tricycle. At that time the only gas engines in existence were heavy, cumbrous prime movers, and built purely for stationary purposes.

A few years later the manufacture of this light Daimler engine was taken up by Messrs. Panhard and Levassor, of Paris, and some of them were exhibited at the 1889 Paris International Exhibition, and attracted considerable attention there. In the affairs of mankind it has been well said that it is only in the retrospect that we can properly appreciate a man's work and put its true value upon it, and looking back over the past 25 years one realises how much the motor car industry owes to Panhard and Levassor, particularly the latter, for the very valuable work which they did in five years prior to 1894 in evolving a practical road carriage to be propelled by the Daimler engine. By that date they had evolved a vehicle which comprised a great many of the essential features of the standard petrol motor car of the present day. For instance, the engine was mounted in front of the vehicle under a bonnet with the starting handle in front. From the engine the power was transmitted through a spring-actuated friction clutch normally in engagement, and disengaged by a pedal for the purpose of changing gear. Changes of gears were obtained by sliding into mesh suitable pairs of spur wheels mounted on parallel shafts. Three speeds and a reverse were provided, and a foot-brake operated by a second pedal, and a second brake operated by a hand lever. There was also a pump for circulating the cooling

water. All these points are standard practice to-day, and are accepted as matters of course, but we should realise what an enormous amount of thought and ingenuity must have been expended upon the problem of conceiving practicable methods of applying the power of the Daimler engine to the propulsion of a road vehicle, and to invent and design suitable mechanism to accomplish these ends. That these devices have stood the test of time is indeed a great compliment to Monsieur Levassor's skill and ability. To refer more particularly to one of these mechanisms, namely, the sliding speed-change gear—this in the early days was greeted on every hand with derision, and an early decease predicted for it. Indeed there are few engineers who have not at some time or other scoffed at its crudeness. Even Monsieur Levassor, when twitted about it, remarked—"*C'est brusque et brutal, mais il marche.*" The fact remains that it is to-day a proved and satisfactory device, and is indeed almost universal practice. With the enormous improvement in materials available since Levassor's day, and attention to the fundamental points of design, the gear-box of a modern vehicle gives little trouble even in the hands of an inexperienced driver, and with a moderate amount of skill gear changing can be effected noiselessly and without shock.

Closely following Levassor's work several other engineers produced motor vehicles propelled by these Daimler engines, or one of similar design, and in 1894 sufficient interest had been aroused to induce the "Petit Journal" to organise a race for motor vehicles between Paris and Rouen, and the laurels were easily carried off by the Daimler engines. There is little doubt that much more attention would have been given to the matter in this country had not the development of the motor car been rendered impossible by the Locomotives on Highways Act, which at that time only permitted a motor vehicle to be used provided it was preceded by a man on foot carrying a red flag, which limited the pace to 4 miles an hour. But for this fact I have no doubt that this country would have had a more

creditable record in the early development of the motor vehicle. In spite of ridiculous and restrictive legislation, however, several progressive men either built motor vehicles of their own design or obtained from the Continent such crude models as were then being manufactured, and set out to evolve more practical motor cars. In the autumn of 1895 one of these experimenters was fined for driving his vehicle in Argyle Street without having a man in front bearing the red flag. It was not until the autumn of 1896 that the law was amended, and motor cars became legal on the highways up to a speed of 12 miles per hour in England and 10 in Scotland. Since that date the industry has gone steadily ahead in this country, though in the early days there was much prejudice to face and many difficulties to be overcome. It was inevitable that large sums of money should be spent on the development of the motor vehicle, which in many cases was entirely lost, and humanity is indebted to the many public-spirited and enterprising men who supported this struggling industry by buying the somewhat crude and certainly, as a rule, noisy and exasperating products of these early days, otherwise the world to-day would not have had the benefit of the great motor-vehicle industry.

The time at our disposal this evening does not permit of an attempt to follow the development of the motor vehicle up to the present day, but a few relative figures may be interesting as showing the advance which has taken place since 1894. The car which won the Paris-Rouen race weighed about 1,300 lbs., and was fitted with an engine developing about 3½ horse-power; it therefore developed 1 horse-power per 370 lbs. of weight. To-day an average allowance for a passenger motor vehicle is about 1 horse-power to 80 lbs. of weight, and a recent writer on this subject hazarded the prediction that, as a result of the influence of the development of aeroplane engines, the ratio would probably be increased to 1 horse-power per 56 lbs. of weight within the next few years. This, however, does not indicate the record which has already been

reached in this direction. Recently a two-seated light car fitted with an air-cooled engine has been put upon the market, which claims to have a ratio of 1 horse-power per 24 lbs. of weight. The early Daimler petrol engine fitted to the first Panhard-Levassor car was a two-cylinder engine operating on the Beau de Rochas cycle, and gave one impulse or working stroke per revolution, but the mechanical balance was poor. A few years later considerable advance was made by the introduction of the four-cylinder engine giving two equally-spaced impulses per revolution, and having a fair balance of moving parts. The great majority of engines used for car propulsion to-day are of this type. About 1903 a considerable advance was made by Messrs. Napier by the introduction of the six-cylinder engine, giving three equally-spaced impulses per revolution, and having a perfect mechanical balance. A properly constructed six-cylinder engine runs with great smoothness, and gives a reasonably equable torque. Quite a number of cars with eight-cylinder engines are now being built, and even twelve-cylinder engined cars are not unknown.

The early motor-car engines only ran well at one speed and approximately full load. This was largely due to the fact that these engines were fitted with carburettors having no automatic regulation, and only supplying a proper mixture to the engine under these conditions. At any other speed or load the mixture was either too rich or too poor to ignite with certainty. The ignition also was by means of hot tubes, which necessitated a fairly constant compression in the cylinders to be effective, and these early engines were consequently controlled by a hit-and-miss type of governor, which either gave the engine a full charge or none at all. The laws governing the flow of air and fuel were investigated, and compensating devices were devised to ensure that the mixture of fuel and air supplied to the engine would be of the desired proportions under all conditions, and some of the later devices attain this in a wonderfully simple fashion. The shortcomings of the hot-tube ignition as fitted

to the earlier engines were soon realised, and within a few years it had entirely given place to electrical ignition. Bearing in mind the difficulties that had to be surmounted in evolving an electric generator of small dimensions and light weight, capable of generating throughout a wide range of speed an electric current at a pressure of several thousand volts, we realise that the modern high-tension magneto is really a

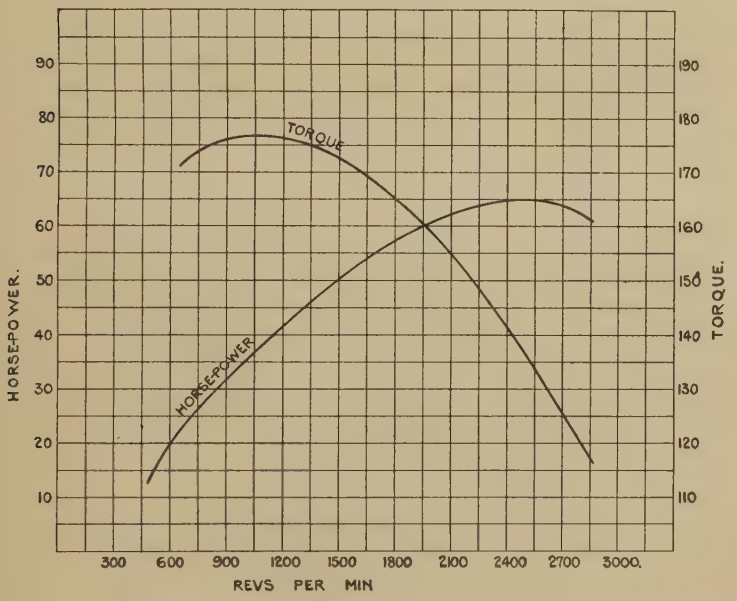

Fig. 1.

marvellous achievement. There are, of course, other systems of electrical ignition, but I have referred to the principal type.

For no very obvious reasons the earliest engines had automatic inlet-valves, but these were unreliable, and were soon replaced by cam-operated valves, which could be relied upon to open and close at the proper periods. From a crude system

depending largely upon splash, the lubrication of engines has been studied down to the minutest detail, and in the best modern practice the lubrication is by pump, and entirely automatic, which only requires attention at infrequent intervals.

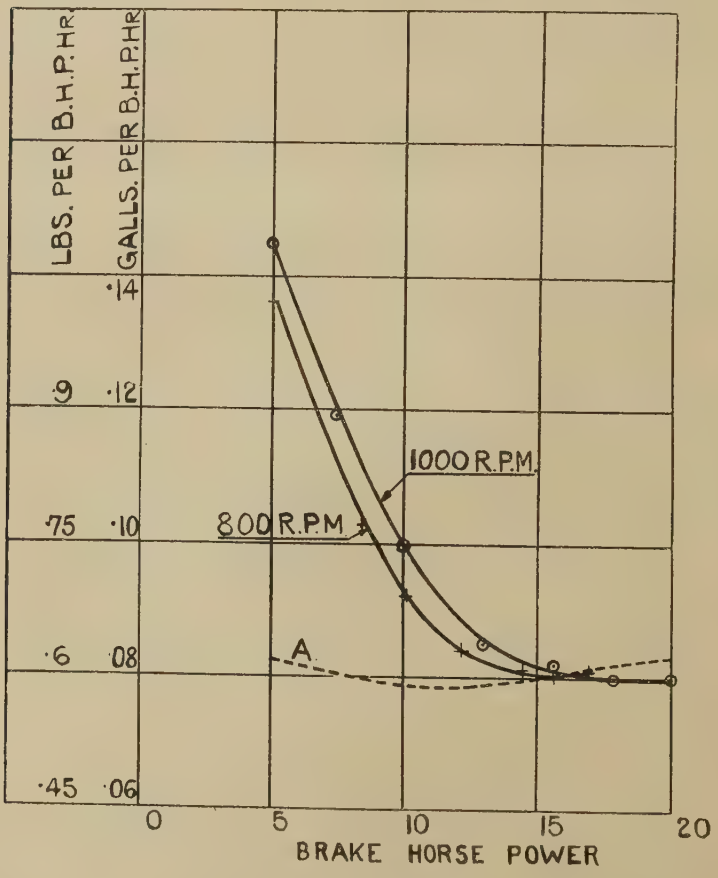

Fig. 2.

The early engines were only capable of a maximum speed of about 1,500 revolutions per minute, but the torque developed at this speed was practically nil, the torque being

a maximum at about 500 revolutions per minute, rapidly dropping off beyond this speed. To-day engines will run comfortably under full load at 2,000 revolutions per minute, and may in some cases be accelerated up to over 3,000 revolutions, the maximum horse-power being developed round about 2,500 revolutions per minute.

Fig. 1 gives the typical brake horse-power and torque curves of a modern motor-car engine.

While the weight of the earliest motor-car engine was approximately 50 lbs. per horse-power, an average figure for a modern engine without fly-wheel may be given as 8 lbs. per brake horse-power, and we may reasonably expect this figure to be reduced to about 5 or 6 lbs. in the future.

The question of fuel economy is an important one in any engine intended for automotive purposes not only because it directly affects the running costs, but where considerable distances are to be traversed, the weight of fuel carried and the size and weight of the necessary tanks become considerable.

The following table shows the brake thermal-efficiences of different types of engines, and from that table it will be seen that the modern motor-car engine occupies a fairly satisfactory position.

Comparative Brake Thermal-Efficiencies.

Locomotives		4 to 6 per cent.
Steam	Compound (non-condensing) including boiler	8 to 12 ,, ,,
	Compound (condensing)	10 to 16 ,, ,,
	Parson's turbine (including boiler)	15 to 18 ,, ,,
Internal Combustion	Petrol (automobile)	22 to 24 ,, ,,
	Petrol (aero)	26 to 28 ,, ,,
	Coal Gas (stationary)	29 to 31 ,, ,,
	Diesel	33 to 35 ,, ,,
Combined I.C. and Steam	Still Engine (efficiency already obtained)	41 ,, ,,
	Still-Diesel combination (probable efficiency)	44·5 ,, ,,

I do not for a moment suggest that we should be satisfied with present attainments, and it is extremely interesting to note the very substantial advance which has been made within recent months in the case of the Still engine.

Owing to the fact that a large amount of reserve power is necessary in a motor-car engine to give rapid acceleration, or to meet the higher tractive effort required for exceptionally heavy-road conditions, or for climbing modern gradients without changing gear, the engine is for the greater part of the time running under considerably less than full load—in fact, for 90 per cent. of the time it may be said to be running at from one-third to one-half full load. Obviously, therefore, it is of great importance that it should have a high fuel efficiency under these conditions. In Fig. 2 is shown the fuel-consumption curve of a normal modern motor-car engine running at 1,000 revolutions per minute, from no load up to full load. At full load the efficiency is good, but at half load the fuel consumed per brake horse-power per hour is 25 per cent greater than at full load. At one-third load the conditions are still worse; the consumption is 60 per cent. greater per brake horse-power per hour than at full load. In fact, over average running conditions the fuel consumption is 50 per cent. greater than the economy attainable at full load. Now, for the conditions I have been describing, the ideal engine should have a fuel-consumption curve somewhat like the dotted line A in the diagram, giving maximum economy from one-third to one-half load, and still a reasonable economy at full load and at no load. Attempts have been made to secure this by providing engines with variable clearance-volumes or by supercharging at full loads, but, so far as I am aware, no conspicuous success has as yet been obtained.

The present engine is far from being ideal, and leaves much room for improvement, one great shortcoming being that it is not self-starting. The mere fitting of a modern so-called

self-starter does not alter the fact that the engine is an inert mass until it is cranked, and this is a serious disability which must be overcome. The ideal engine for vehicle propulsion would be one which was reversible, really self-starting, and having an emergency torque about three or four times the normal, such as, for instance, is obtained in a compound engine by admitting steam to the low-pressure cylinder. It goes without saying, of course, that it must be light, simple in design, require next to no attention, be moderate in cost, and reliable and economical in service. The ideal engine which doubtless will be ultimately evolved may quite probably be an entire departure from the internal combustion type as it is known to-day.

While the question of the speed of a vehicle on the road is not of primary importance, it is perhaps the feature which ranks foremost in the public conception. In this connection, we find a very curious analogy between public opinion as to the safe speed on railways in early days, and public opinion 70 years later in connection with the speed of motor vehicles. When in 1821 the first railway between Liverpool and Manchester was projected by the great engineer, George Stephenson, the fact that he proposed to work the line with an engine running at 12 miles per hour was held up as of itself sufficient to stamp the scheme as a bubble. "Twelve miles an hour!" exclaimed the "Quarterly Review," "as well trust oneself to be fired off on a Congreve rocket." Experience soon proved, however, that these fears were groundless, but that did not prevent very similar fears being expressed in 1896, and as a result, when motor cars were first legalised on Scottish roads, the speed was limited to 10 miles an hour, although in a few years that was raised to the more reasonable limit of 20 miles an hour, and but for thoughtless and inconsiderate driving in a few isolated cases, this limit might ere now have been considerably increased.

Having these facts in view, it is extremely interesting to

note that, in 1894, in the Paris-Rouen race, the average speed of the winning car was 12 miles per hour; whereas, in the Grand Prix of 1914, over a difficult course extending to 466 miles, an average speed of 65 miles per hour was attained; while in the spring of this year, on a motor racing track, the mile was covered in 24·02 seconds, representing a speed of 149·8 miles per hour.

In the short space of a quarter of a century the safe speed of passenger transit on ordinary roads has been practically quadrupled. In future, when we have, as we no doubt will have, special motor-vehicle highways with recognised up and down tracks probably running over and under bridges to eliminate the crossing dangers of other intersecting highways, the speed of motor vehicles on these roads will at least equal that of express trains to-day, and with perfect safety.

Before leaving the question of speed, it should be noted that the question of rapid acceleration is an important one for the motor-car designer. Under ordinary road traffic conditions it is, of course, impossible to maintain a constant velocity from start to finish of the journey. A modern high-grade passenger motor car is capable of acceleration on the level from a speed of 10 miles per hour to a speed of 30 miles per hour in about 10 seconds, and this capacity for rapid acceleration has a very important bearing on the total time required for any given journey. It also has an important psychological effect on the driver, as the knowledge that he can rapidly regain a high speed makes him much more willing to reduce the speed to well within safe limits whenever occasion demands.

One of the most notable developments of the past 25 years has been in the materials available for construction. While in the early years of the motor-car industry a good quality of mild steel was practically all that was commercially obtainable, to-day we have a large choice of alloy steels which has enabled designers in many cases to cut down the weight

of a part to one-third of what it would necessarily have been with the older materials.

The accompanying table shows the enormous advance which has been made in the production of high-grade constructional steels.

COMPARATIVE PHYSICAL PROPERTIES OF STEEL.

	Ultimate	Yield.	Elongation in 2 inches.	Reduction of area.
	Tons.	Tons.	Per cent.	Per cent.
Medium carbon steel (normalised) -	30	16	25	45
Bright drawn mild-steel bars. Air Board Specification S1, Part 1	35/42	25	15	40
3 per cent. nickel steel bars (heat treat.). Air Board Specification S8 - -	45	32	24	50
Nickel chrome (heat treated). Air Board Specification S11 - -	55/65	45	18	50
5 per cent. nickel case-hardening steel. Air Board Specification 3S 17 -	60	50	13	40
100-ton alloy steel bars. Air Board Specification S18 - -	100	—	8	20
Chrome vanadium spring steel -	115	110	10	—
Special alloy steel for gears, etc. -	134	106	8	15

Again, in modern engineering the designer has not only a much better knowledge of the materials he is employing, but he can rely upon their being homogeneous and really having the physical properties set out in the specification, and, therefore, it is unnecessary to use such generous factors of safety as were usual in the earliest days.

Where the designer is dealing with the problem of motor vehicle or similar structures in which saving of weight is of supreme importance, he must carefully discriminate in the case of each part, and employ only such a factor of safety as is necessary, having in view the point as to whether

the structure is only subjected to such a stress as can be accurately estimated, or whether it may be liable to severe overload stresses due to shock. To take a concrete instance, consider the case of a foot-brake lever. Here it is known that the maximum stress which can be imposed is the pressure exerted by the man's foot, and if we take a maximum figure for this it is sufficient to allow a factor of safety of two with respect to the yield point of the material. While in mild steel we dare only stress the part up to $7\frac{1}{2}$ tons per square inch, with 3 per cent. nickel steel we can go to 20 tons, and with nickel chrome steel we can go to 30 tons per square inch. On the other hand, there are parts such as axles where the dead-load stresses may only represent as little as 8 per cent. of the maximum stresses which may be imposed by exceptionally severe road conditions, and the impossibility of contending with such conditions without the use of these special alloy steels will be readily appreciated.

Prior to the advent of motor engineering, the accepted dimensions and basis of design for machine-cut gearing were such as to have made the motor car an impossible proposition. To give a single instance: an electric crane reduction-gear transmitting 30 horse-power at a pitch-line speed of 750 feet per minute, with velocity ratio between the two shafts of three to one—the gears being machine cut of steel—an average size for the teeth was one inch circumferential pitch by $2\frac{7}{8}$ inches wide. In a modern motor car gear-box, having machine-cut wheels of case-hardened special alloy steel with the same pitch-line speed transmitting the same power, and with the same speed ratio between the shafts, the following dimensions would be found very ample:—·63 inch circumferential pitch by one inch wide, and the relative weights of the two sets of gears would be in the one case 95 lbs. and in the other 11 lbs.; in other words, the weight of the motor-car gear is less than 12 per cent. of the weight of the electric-crane gear. Where in aircraft design the weight is of supreme

importance, by the adoption of still higher-grade materials still greater reduction in weight can be achieved. I do not suggest that all this reduction in weight is due to better materials; probably the two most important factors are the steps that are taken to harden the wearing surfaces of the teeth, so as to carry the enormous loads without deformation or abrasion, and the accuracy with which the teeth are formed and finished, and, in a lesser measure, the precautions which are taken to maintain correct relative position and alignment of the shafts to eliminate deflections and vibrations.

To obtain full advantages of these various alloy steels very special and accurate heat treatment is necessary at various stages of the manufacturing processes. The heat-treating department in a modern motor-car factory is a section of primary importance in charge of a technical expert, and in close touch with the works' laboratory. It embraces a variety of furnaces of different types for normalising, carbonising, reheating, and tempering. The trend of design of furnaces would appear to be towards the producer-gas type. The control of the temperature is of vital importance, and in the case of some steels the temperature for a given treatment must be kept within very narrow limits.

The determination of temperature is almost entirely done by means of electrical pyrometers, preferably of the recording type, so that the life history of any batch can be referred to at a subsequent date, if necessary. Batteries of cooling baths are also provided to suit each particular process, and these are carefully maintained at the required temperature.

Fig. 3, which is taken from a paper read recently by Mr. Arthur Stubbs, shows graphically the extreme importance of the correct temperature and the proper methods of cooling if the material is to have the physical properties desired for the particular duty it is called upon to perform. Failure to observe these conditions may produce most disastrous and totally unexpected results. As an instance, similar pieces

of nickel chrome steel were reheated to 600° C., the one water quenched and the other allowed to cool slowly; the

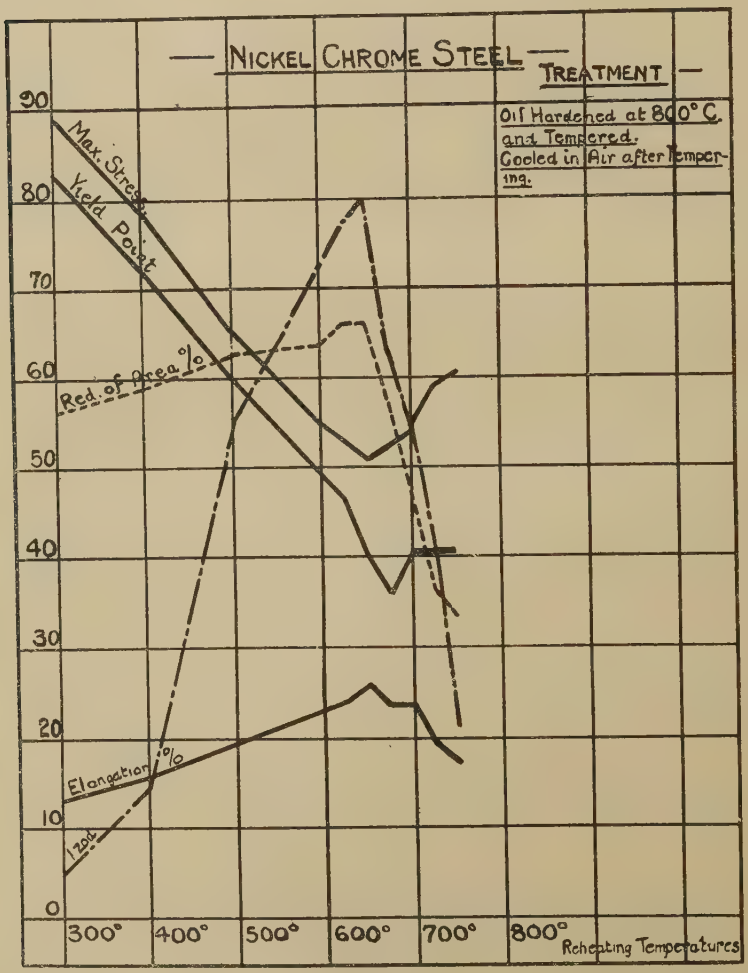

Fig. 3.

sample which was water quenched gave an Izod test of 52 foot-lbs., whereas the slowly-cooled test-piece gave an Izod

test of 1 foot-lb. The great danger lies in the fact that this extreme brittleness of the slowly-cooled sample would not have been disclosed by an ordinary tensile test.

An extremely useful adjunct to the heat-treating department is the copper-plating shop. By this means the case-hardening effects can be located as desired on machined parts. By proper hardening and tempering one is able to vary the relation between the ultimate tensile strength, the elastic limit, elongation, and reduction in area, and to obtain with certainty the combination most suitable for the purpose in hand.

It is to the metallurgist that the engineer is indebted for the great progress that has been made in materials during the past decade, and it is to the collaboration of the engineer and metallurgist in the future that we must look for new and improved alloys and suitable methods of treating them.

I cannot leave the subject of materials without referring to aluminium alloys. These are playing an increasingly important part in the construction of motor vehicles and aircraft. These alloys are largely employed in the construction of engine-cases, gear-boxes, etc., and more recently pistons have been largely made of this material. For this latter work they have the two important advantages of lightness and high heat-conductivity. To mention in particular one of these, duralumin is an alloy containing upwards of 90 per cent. of aluminium, and has a specific gravity of 2·8 as compared with 7·8 for steel. In the hull construction of R34 16 tons of duralumin were used. According to the purpose for which it is intended, duralumin can be supplied in qualities ranging from an ultimate tensile strength of 25 tons per square inch with 25 per cent. elongation, to 35 tons per square inch with little elongation, the elastic limits being 13·5 and 20 to 27 tons per square inch respectively. The Brinell number for duralumin plates varies from 109 to 174, the higher value being for thin, and consequently hard, plates.

Particulars of a new light-piston alloy appeared a few weeks ago in an American technical journal. Its chief constituent is magnesium, which has a specific gravity of 1·74. This new alloy is claimed to be specially suitable for pistons. Its elastic limit is from 5½ to 6½ tons per square inch, and its ultimate tensile strength from 7 to 8½ tons per square inch. It is further claimed to possess a low coefficient of expansion and high heat-conductivity; is easily machined, and less abrasive on the cylinder walls than aluminium. We may look with confidence for still further substantial advances both in alloy steels and light constructional alloys. Progress in the past is only indicative of what will certainly be achieved in the near future.

Let us attempt to visualise the motor road-vehicle of the future, and the conditions under which it will have to work, say, 20 or 30 years hence. The recent railway strike brought home to the public the capabilities of mechanical transport, and before long the enormous importance to the prosperity of the nation of the highest possible grade of highway will be fully realised. There is probably no other national investment which will ultimately show a more handsome return.

One of the difficult and most important problems to be tackled by civil engineers is the method of constructing highways so that they will require a minimum of upkeep and provide a smooth and clean surface for traffic. The road of the future will be proportionately broad to the traffic it has to carry. It will be so constructed as to be practically dustless, and there will be an absolute prohibition against any other than rubber-tyred traffic. Neither horses nor other animals will be permitted on its surface. If they are to be transported over them, it must be in trucks suitable for the purpose, as is done in railway work to-day. It will then seem just as reasonable to suggest driving a flock of sheep along one of these main highways, as it would appear to us to-day were a farmer suggesting to drive a flock of sheep along a railway

line. Traction engines and agricultural implements and such like will not be allowed to destroy the surface as they do at present. Sharp bends will be eliminated, and on main highways few gradients will exceed 1 in 20, and even on subsidiary roads greater gradients than 1 in 10 will probably not be permitted. The surface of these roads will also be maintained at a certain definite standard determined probably by some species of seismograph, and there will be no such thing as the road waves and pot holes with which to-day we are all so painfully familiar. A private owner will, in fact, have legal redress against the authorities should his vehicle be damaged through defective road surfaces. While discussing the question of roads, it will be interesting to compare, for a moment, the tractive effort necessary under various conditions. The following table gives the tractive effort required in pounds per ton to overcome road resistance:—

TRACTIVE EFFORT REQUIRED TO OVERCOME RAIL OR ROAD RESISTANCE.

RAILWAYS.	lbs. per ton.
Main-line railways	15
Electric tramways	26-30
ROAD SURFACES.	
Asphalt on concrete	40-45
Smooth granite setts	50
Tar Macadam, hard	65-70
Clean wood pavement	70
Tar Macadam, muddy and sticky	95
Road metal, partly rolled	120
Tar Macadam, soft and cut up	140
Unrolled road metal	200

This shows conclusively that the question of road surface is of paramount importance and has a direct bearing on the cost of transport, and no effort should be spared to obtain the

most efficient road surfaces. When it is borne in mind that a gradient of 1 in 20 necessitates an additional tractive effort of 112 lbs. per ton, it becomes abundantly clear that, the difference in tractive effort required to haul a rubber-tyred vehicle on a first-class road as compared with an electric tramway is so moderate as to be practically negligible. On further reflection it would seem difficult to find any reasonable excuse for the retention of tramway cars, more particularly as they form a most serious obstruction to other traffic in the streets of a town or on a highway, owing to the lack of dirigibility, and the tramway lines form a fruitful source of damage to road surfaces, and constitute also a frequent cause of tyre damage and side slips.

When really good roads are an accomplished fact it will no longer be necessary to have a gear-box or its equivalent in motor vehicles, and it is quite possible that it will be unnecessary in the lighter vehicles at least to provide anything in the nature of a differential gear, as the coefficient of friction between the tyres and the roadway will not be such as to prevent the slight amount of slipping necessary to take place without damaging the tyres.

The gradual improvement in roads will react very materially upon the design and the weight of motor vehicles. At present we are compelled to design vehicles sufficiently strong to withstand the worst conditions under which they may have to work, and in some cases the conditions are very extreme. When one can rely upon reasonably good highways much lighter construction will be possible throughout, and every pound saved in weight reacts through the whole design and throughout the life history and efficiency of the vehicle.

One great problem which demands the closest attention of the engineer is the conservation of our fuel supplies. We cannot go on as we have done in the past. The rate of consumption has been rapidly rising, as has also the cost, and supplies are far from being unlimited. Our duty, therefore, to

future generations demands that the most strenuous efforts be made to conserve every ton of fuel, to increase the efficiency of thermal engines, and the various manufacturing processes in order that this end may be attained.

As long ago as 1886, Prof. J. P. Lesley, addressing a meeting of the Institute of Mining Engineers in Pittsburg, said:—"I am no geologist if it be true that the manufacture of oil in the laboratory of Nature is still going on at the hundredth or the thousandth part of the rate of its exhaustion. And the science of geology may as well be abandoned as a guide if events prove that such a production of oil in Western Pennsylvania as our statistics exhibit can continue for successive generations. It cannot be. There is a limited amount. Our children will merely and with difficulty drain the dregs."

It should be clearly borne in mind that we have been in the past, and are at present, living upon capital; this, as every business man knows, is a prodigal policy, and sooner or later will lead to bankruptcy. In other words, we must live on revenue—that is to say, we must year by year obtain in some manner or other our annual supply of fuel either from agriculture or some other natural source of production. Here it is appropriate that I should make a brief reference to the possibilities of alcohol as a fuel and the report recently issued by the Government Alcohol Committee. With the desire of fostering home production and fuel for motor vehicles, France has for years past devoted a large amount of attention to the question of running internal combustion engines on alcohol, with considerable success. In the French War Office trials, carried out in 1910, the following very interesting results were obtained:—

Petrol - -	53·2	gross ton-miles per gallon.
Alcohol fuel -	46·3	,, ,, ,, ,,
Benzol - -	57·1	,, ,, ,, ,,

The alcohol fuel was a mixture consisting approximately of

50 per cent. alcohol, 35 per cent. benzol, and 15 per cent. petrol.

Taking alcohol at 1s. 3d., benzol at 1s. 10d., and petrol at 1s. 11½d. per gallon, the cost per ton-mile works out at ·45d. for petrol, ·412d. for alcohol fuel, and ·385d. for benzol.

It has been clearly demonstrated that alcohol alone, or a mixture of alcohol and petrol or similar fuels are quite suitable for the propulsion of motor vehicles, and there seems to be little doubt that alcohol will be one of the most important fuels in the future. Its merits are summarised in the following sentence taken from the British Government Committee's report:—

"The outstanding and fundamental attraction of alcohol motor fuel as a substitute for any fuel necessarily derived from coal or oil deposits lies in the fact that, on account of its chief sources being found in the vegetable world, supplies of raw material for its manufacture are being continuously renewed, and are susceptible of great expansion without encroachment upon food supplies."

While the prospect of commercial production in Great Britain is not encouraging, there is every possibility that the necessary supplies of alcohol fuel could be produced within the British Empire, the raw material being obtained from tropical countries. The vegetable materials from which alcohol may be produced are so varied and widespread that there would appear to be almost no limit to supplies. There are sugar-containing products, such as molasses, large quantities of which are at present running to waste; starch-containing products, such as cereals, potatoes, etc.; and cellulose-containing products such as wood pulp.

Dr. Ormandy, in a paper read in 1913, instanced a plant intended for British Nyassaland capable of producing 600 gallons of alcohol per week from maize. The cost of the raw material only amounted to 3d. per gallon of alcohol. The other charges he estimated at 6d. per gallon, making a total

cost of 9d. per gallon at the distillery. This, however, as he pointed out, is a very small plant, and from the figures given by other authorities there seems to be little doubt that alcohol can be produced at from 5d. to 6d. per gallon at the distillery. In the recent Government Alcohol Committee's Report there is indicated a very promising source—namely, flowers of the mahua tree. These the Committee stated could be cultivated and delivered at the local distillery at 30s. per ton, which would represent a raw material cost of 4d. per gallon. Given, therefore, reasonable excise regulations, which will no doubt come in time, there seems to be no reason why denatured alcohol fuel should not be delivered to the consumer at about 1s. 3d. per gallon.

The following table shows the comparative properties of denatured alcohol, petrol, and paraffin, and the cost per brake horse-power per hour with these fuels:—

Cost Per B.H.P. Per Hour on Various Fuels.

Fuel.	B.Th.U's. per lb.	Brake Thermal Efficiency.	Lbs. per B.H.P. per hour.	Specific Gravity.	Gallons per B.H.P. per hour.	Price per gallon.	Cost per B.H.P. per hour.
		Per cent.					
Denatured Alcohol	11,000	30	·77	·825	·093	1/3	1·40d.
Petrol -	19,000	23	·58	·780	·075	1/11½	1·76d.
Paraffin -	20,000	20	·64	·810	·079	1/6	1·42d.

Note.—Government taxes have not been included in the prices which are for the fuels delivered in bulk. For alcohol, the price per gallon comprises 6d. for manufacture and 9d. for distribution.

Steps must also be taken to fully utilise our natural sources of energy, such as waterfalls. We may even be compelled to

devise satisfactory ways and means of obtaining mechanical energy from such sources as solar heat, wind, and tides.

Perhaps the most interesting field of application of the internal combustion engine, and certainly the most romantic, is in the realm of flight. From the earliest ages it has been man's ambition to conquer the air, and one can scarcely realise that little more than a decade has elapsed since the brothers Wilbur and Orville Wright first accomplished a flight in a machine heavier than air driven by a petrol engine. In this field, particularly during the war, development of design has been astonishingly rapid, and one might say with truth that the results achieved have been almost miraculous. While the Wright brothers began with an engine developing 15 horse-power, aeroplanes are being constructed to-day with one or more engines each developing 400 or 500 horse-power. One of the most successful engines of modern design develops 450 horse-power, and only weighs 662 lbs., or rather less than 1½ lbs. per horse-power. Even when an engineer accustomed to motor-vehicle practice, which is thought to combine maximum lightness consistent with safety, is first brought into contact with these latter-day aero engines, he stands aghast to see how fine the limits of weight have been cut. It was stated in a recent publication that the weight-carrying capacity of a modern aeroplane is about 33 per cent. of the total weight. It is not unreasonable to assume that in the next few years this percentage should be raised to at least 50, and upon this assumption it ought then to be possible to construct an aeroplane capable of carrying one man and sufficient fuel for a short journey, having a total weight of 150 lbs. The engine would probably be about 20 horse-power, of the air-cooled type, weighing not more than 20 lbs. A few years hence, therefore, we may see practical machines offered on the market enabling a man to fly from point to point with as great ease as he would cover the distance on a motor bicycle to-day. Great progress will doubtless be

made in the construction of larger aeroplanes and in their commercial use, though it must be borne in mind that the manipulation of these machines will always require a much higher degree of physical efficiency than is necessary for the control of vehicles running on land or water, as the landing of an aeroplane must always call for a cool head and sound judgment. Simultaneously with the development of the heavier-than-air machine, great progress has been made in the construction of lighter-than-air craft, and I need only refer to the magnificent feat of the Clyde-built airship R34 in crossing and recrossing the Atlantic a few months ago. It may safely be said that the rate of evolution of aircraft will largely depend upon the progress that is made in evolving new and improved prime movers. Undoubtedly the field here offered to the young engineer is illimitable.

One of the most impressive illustrations of the modern development of the light internal-combustion engine is the extent to which it was used, and the part it played, in the great war. In the air the petrol engine alone served for the propulsion of airships, aeroplanes, and flying boats. On the land it was principally used for the propulsion of either passenger- or goods-carrying vehicles or engines of war, such as tanks; and also for a large number of other purposes where a light portable prime-mover was necessary. On the sea it was utilised for the propulsion of motor boats and various small craft, as well as for auxiliary purposes. At the conclusion of hostilities the British War Department had 62,000 motor lorries, 28,000 cars, and 33,000 motor cycles.

By the courtesy of the Ministry of Munitions I am able to give a statement of the total horse-power represented by the output of internal combustion engines by British manufacturers during the war.

The table is divided into three sections—namely, aero engines, mechanical transport engines, and tank engines; of the former the total production during the war amounted to

ENGINES PRODUCED 1914-1918 IN TERMS OF HORSE-POWER.

Type.	Aug.-Dec. 1914.	1915.	1916.	1917.	1918.	Total.
Aero engines -	12,000	195,000	771,000	1,973,000	4,143,000	7,094,000
Mechanical transport engines -	—	—	137,000*	683,000	662,000	1,482,000
Tank engines -	—	—	16,000	133,000	191,000	340,000
	12,000	195,000	924,000	2,789,000	4,996,000	8,916,000

* Four months, September to December, only.

the enormous figure of 7,094,000 horse-power. Dealing with mechanical transport engines, the table does not give the figures for the years 1914 and 1915, but these aggregate about three-quarters of a million horse-power, and, therefore, the total brake horse-power of mechanical transport engines produced for war purposes was 2,232,000. For tank engines the total was 340,000 horse-power, making a grand total for all classes of 9,666,000 horse-power. A prime mover that has so wide and general an application merits the closest attention, and no effort should be spared to improve it.

While there has been great progress in the last 25 years in the constructional materials available for the engineer, there has also been a great development in machine-tool practice generally, and especially in the evolution of tools for the production of parts in quantity in a cheap and efficient manner, and of such high-grade accuracy as to be interchangeable. Time only permits a very brief reference to this interesting subject, but perhaps the advance made in automatic grinding-

machinery is one of the most interesting developments. Not only has the grinding machine made it possible to produce with ease complicated parts such as multiple-throw crank shafts with an accuracy unapproachable even by a skilled turner, but also at far lower cost. In the process of case-hardening, a certain amount of permanent distortion inevitably takes place, and in no other way could this be rectified than by the use of automatic grinding-machines. Brought to a high state of perfection, they can deal with practically any form of surface, flat, circular, internal or external, or of irregular shape, such as cams for operating inlet and exhaust valves. Such cams can be produced commercially to a limit of accuracy of $\frac{1}{1000}$ inch. In fact, where drop forgings are used it is no uncommon practice to dispense with the lathe entirely, and to machine and finish such parts as crank shafts and cam-shafts right from the forging on grinding-machines. Considerable success has also been achieved in automatic grinding-machines to rectify the teeth of hardened gear-wheels, where the slight distortion that almost inevitably takes place under heat treatment would otherwise set up undesirable noise.

In motor car work the diameter of the shafts is so small in proportion to the torque transmitted that the old-fashioned methods of keying are insufficient. The best modern practice is to machine 6, 8, or more key-ways equally spaced on the shaft, and these, after hardening, can be rectified or ground to accurate dimensons in suitable automatic grinding-machines.

Broaching or drifting machines are being increasingly used for producing all shapes, or holes, such as the castellated holes in the bosses of wheel parts to be mounted on a castellated shaft such as I have been describing. It is even claimed that ordinary bushes can be bored more cheaply and accurately by this means than by any other.

I cannot omit a reference to the great advance which has been made by the introduction of what is known as high-speed

steel for cutting tools. As the accompanying table shows, it permitted cutting speeds to be very substantially increased, and it enabled much heavier cuts to be taken—two facts which very soon led to the complete redesign of machine tools. Much

	Medium steel forgings.	Hard steel forgings.	Hard cast iron.
	Feet per min.	Feet per min.	Feet per min.
Carbon tool steel, 1894 -	16	6	15′ 6″
High-speed steel, 1906 -	99	41·5	52′ 0″
Increase - - -	6 times.	7 times.	3 times.

stiffer tools were required, tools running at a higher speed and of much more rigid design, so that full advantage could be taken of the new steels.

Wherever a highly-specialised piece of machinery is to be produced in quantity, the aim of the engineer must be to confine skilled labour to the tool room, and in the factory proper the tools must be as nearly automatic as possible, and should also be, as far as practicable, single-purpose tools so as to avoid all unnecessary complication in their construction. They should, in fact, eliminate the necessity for jigs by becoming in themselves live jigs, designed and constructed to carry out special operations on the particular part and nothing else.

It must ever be the engineer's aim to cut down the time required for the production of any given part to a minimum; therefore, as far as possible, similar operations on a part should proceed simultaneously. For instance, multiple head milling-machines are now built which will surface three or four faces on, say, a cylinder block simultaneously at one setting. Again, in a succeeding operation it may be necessary to drill upwards of 50 holes in the said cylinder block distributed on three or four surfaces. Machines are now constructed

which will bore all these holes simultaneously at one setting. This indicates the direction in which evolution is tending, and wherever the quantities to be produced warrant the expense, it is the correct policy to adopt. It is in this connection that standardisation of parts is not only of immense value to the engineer, but equally so to the benefit of the community at large. A policy of standardisation must, however, be pursued with caution, for there is a tendency when standards are fixed to adhere slavishly to them with the inevitable result that progress is thwarted, and new and improved methods are thereby rendered more difficult of introduction. A standard design should only be retained so long as it is clearly the best adapted for the particular purpose. The great advances made both in automatic machines and semi-automatic machines have made it possible to turn out cheaply accurate parts which, under conditions existing 25 years ago, could only have been made by highly-skilled workmen, and then only at prohibitive prices.

The aim of the engineer must be to carry out all operations calling for no brain effort by automatic machinery, and as far as possible to stimulate the interest of the workman by giving him work which calls for mental as well as muscular effort.

While not belittling for a moment what has been achieved, the product of the automatic tool still, as a rule, leaves something to be desired. To be entirely satisfactory it must finish off the article with all necessary fillets, male and female, and all rags of every kind must be automatically removed so that the part passes on to the finished parts' store, and ultimately to the erector, then into its place without any file, reamer, or scraper touching any portion of it. We may look forward to seeing all the hand-abrasive-tools banished under penalty from the erecting shop of the future. The higher the efficiency, accuracy, and interchangeability that is obtained in the machine shop, the lower will be the ultimate

cost of the article. It is only the country whose engineering factories adopt the higher standards that will be able to compete successfully in the markets of the world.

The present year marks such an interesting epoch in the history of mechanical engineering that I cannot omit a reference to it, however short, before concluding my remarks. I refer to the fact that this year marks the centenary of the death of James Watt, the patron saint of our Institution, and probably the greatest mechanical engineer the world has ever seen, and one who has done more by his inventions to benefit mankind than any other before or since. The life and work of James Watt are so well known that it is unnecessary for me to enter into any detail, but there is one point which is of peculiar interest to us in this city—namely, that it was the University of Glasgow which gave sanctuary to James Watt at a time when the Guild of Hammermen of Glasgow would not permit him to open a shop and start work in the city. It was while working under academic protection, and in the classical atmosphere of the University quadrangle, that he was called upon to repair a model of the Newcomen steam engine. He soon realised the low efficiency of this engine, and set to work to investigate matters both as an engineer and a man of science. As the reasoned result of these investigations and experiments, he conceived and invented the separate condenser.

The more one studies the life of James Watt the greater does one's admiration of his genius become, and one marvels at the wide scope of his activities and at the enormous amount of work he was able to achieve. He may be said to have laid the foundation of modern scientific engineering, and it is only fitting that as an Institution we should make an effort to adequately commemorate the centenary of his death. After careful deliberation, your Council have come to the conclusion that the most appropriate manner in which to commemorate his life and work would be to raise a fund of £50,000 to endow

an additional Chair of Engineering in Glasgow University. Such a Chair would not only be a further monument to Watt's memory, but would have the great utilitarian advantage of providing facilities for the teaching of young engineers in the highest branches of our profession. The appeal issued by the Institution has already received a response amounting to £22,000, and it is with confidence that I now recommend the scheme to the sympathetic consideration of each of our members, satisfied as I am that not one of us will rest content until the desired goal has been achieved.

PHOTO-ELASTIC AND STRAIN MEASUREMENTS OF THE EFFECTS OF CIRCULAR HOLES ON THE DISTRIBUTION OF STRESS IN TENSION MEMBERS.

By Prof. E. G. Coker, M.A., D.Sc., F.R.S., K. C. Chakko, M.Sc., and Y. Satake, University College, London

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18th November, 1919.

The effect of a hole on the stress distribution in a tension member of rectangular section is of considerable importance in practical work, since in nearly all engineering operations holes are drilled or otherwise shaped for connecting pieces together, and although in most cases the stress is applied by a rivet filling the hole, yet there are numerous instances in practical work in which the experiments, to be described, are very closely represented. In roof trusses and bridges, for example, compression and tension angle bars and rectangular tension members often occur in pairs, and are held together at intervals by rivets, which latter usually transmit no forces to the members themselves. Other instances of a more complicated kind occur in the frames of machines in which groups of elements, connected by bolts and rivets, are unavoidably diminished in section by holes for constructional reasons. Most of these cases are more complicated than those investigated here, but there is a certain amount of advantage in selecting simple cases for experiment, since the general character of the stress distribution is more easily perceived, and its application to more involved cases is likely to be attended with less error, than if an attempt is made to use the investigation of one complicated example to

another case in which the various circumstances which cause the complexity are of a different nature. Simplicity in the conditions is, in fact, most essential for real progress in experimental knowledge, and especially so in connection with problems on stress distribution in materials.

Engineers endeavour to avoid stressing materials beyond their elastic range, so far as that is possible, and with this limitation the general theory of stress distribution in materials is very complete, although the great majority of problems, of special interest to engineers, still remain unsolved.

So far as is known, the distribution of stress produced by a central hole in a tension member of finite width has not been worked out as a purely mathematical problem, although the problem has been successfully attacked for both circular and elliptical holes in plates of infinite width on the usual assumption of elastic theory.* The theoretical solution for a circular hole in an infinitely wide tension member is important, and some reference to it is necessary here. A solution of the problem is therefore given in Appendix A.

Experimental determinations of the stress distribution around a hole in elastic materials have been made by various investigators, such as those by Messrs. Wilson and Gore, in which the strains are measured in perforated rubber sheets. In a recent paper† the stress around a hole in a tension member, which is permanently deformed, is considered by determining the hardness of the surface of the material at various points. It is there shown that hardness increases with tensile stress, according to a linear law, after the elastic limit has been passed.

* C. E. Inglis—"Stresses in a Plate Due to the Presence of Cracks and Sharp Corners." Trans. Institution of Naval Architects, 1913. See also A. E. H. Love—"Treatise on the Theory of Elasticity," 1st Edition, Vol. i, chap. xii; and H. Lorenz—"Lehrbuch der Technischen Physik," Vol. iv, Art. 55.

† "Stress Lines in Steel After Permanent Deformation," by Andrew McCance, D.Sc., A.R.S.M. Trans. Institution of Engineers and Shipbuilders in Scotland, Vol. lxii.

Curves of equal hardness are drawn for over-stressed material, and the stress at any point is apparently inferred by the relation previously established between hardness and the stress in a bar of uniform section permanently deformed by tension. It seems probable that our scanty knowledge of the stresses in materials in the plastic stage may be appreciably extended by this method.

The present paper is an extension of some experimental work,* undertaken by one of us on transparent plates to find the nature of the distribution around a circular hole. This earlier work was manifestly incomplete, since no attempt was then made to separately determine the principal stresses P, Q at a point, and only the value $(P - Q)$ was measured by aid of the change in the temporary double refraction produced by stress. The theory of the infinite plate shows that the minor principal stress is comparatively small, and indeed vanishes altogether at the internal contour where the stress reaches its maximum value and also at the parallel sides, so that, from a practical point of view, little was lost by the limitation of the earlier work, although there remained a number of interesting questions, requiring much precise measurement, especially for the determination of the $f(P, Q)$ which would allow of separate measurements of P, Q, and their inclinations λ_p, λ_q, and so complete the experimental analysis. The methods and apparatus used are described in earlier papers,† and need not be referred to here.

For convenience, sheets of nitro-cellulose were used, as in previous work, and some of the specimens tested were originally

* "The Determination, by Photo-Elastic Methods, of the Distribution of Stress in Plates of Variable Section, with Some Application to Ships' Plating," by E. G. Coker. Trans. Institution of Naval Architects, 1911. Also, "The Effects of Holes and Semi-Circular Notches on the Distribution of Stress in Tension Members," by E. G. Coker. Proc. Physical Society, London, Vol. xxv, 1913.

† E. G. Coker—"Polarised Light and its Applications to Engineering," Royal Institution, Friday evening discourse, 1916, and "Photo-Elasticity for Engineers." Proc. Institution of Automobile Engineers, November, 1917.

Fig. 1.

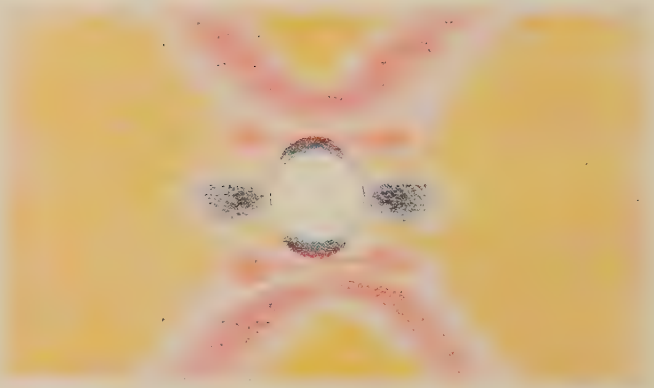


Fig. 2.

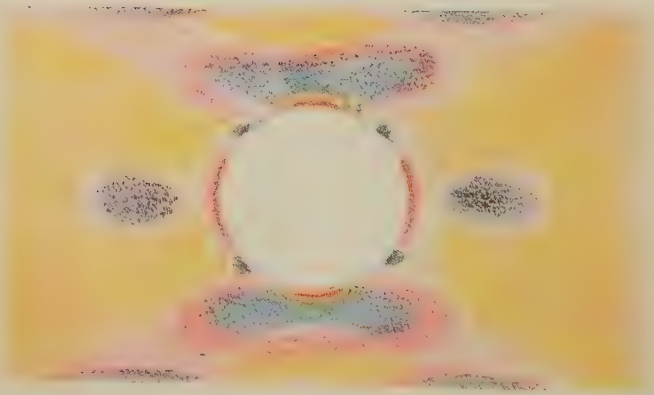


Fig. 3.

made in 1911. The $(P-Q)$ stresses are independently measured, and, as the results show by comparison with the earlier figures, the ageing effect in the material is very small. One of the questions to which the present investigation is directed relates to the contour value along the parallel sides, and around a centrally placed hole. In both cases, since there are no applied forces at these contours, there can be no normal stress there, while these boundaries are themselves lines of principal stress, to which the other principal stress curves are orthogonal. The values of $(P+Q)$ and $(P-Q)$ therefore coincide along these contours, and may be used to check one another in an experimental determination.

A qualitative examination of holes of various sizes in a finite width of plate shows that at the straight boundaries the maximum stress in the direction of the pull is not necessarily at the minimum section. This is apparent from the appearance of specimens in which the hole is enlarged progressively. With a hole of $\frac{1}{16}$ inch diameter, Fig. 1, in a plate of 1 inch width there is no visible indication of any variation of stress along the external contours, but if the hole is enlarged to, say, $\frac{1}{4}$ inch diameter, Fig. 2, it is at once evident from the colour bands that there is a non-uniform distribution of stress along the sides with maximum values on each side of the minimum section. As the hole is further enlarged, Fig. 3, this unequal distribution of stress becomes increasingly apparent. Before proceeding to a quantitative examination of the stress along these contours, it is of interest to find what is the distribution in the neighbourhood of a hole in the case of an infinite plate, in a form convenient for comparison with experiment, and this may be accomplished by a semi-graphical process.

The principal stresses P, Q may be determined from the polar components given by Equation 7 of Appendix A in the following manner. It can be readily shown that

$$P+Q = \widehat{rr}+\widehat{\theta\theta}$$

$$P-Q = \sqrt{(\widehat{rr}-\widehat{\theta\theta})^2+4\cdot\widehat{r\theta}^2}$$

$$\tan 2\phi = \frac{2\,\widehat{r\theta}}{\widehat{rr} - \widehat{\theta\theta}} = \frac{\left(1 + \frac{2}{r^2} - \frac{3}{r^4}\right) \sin 2\theta}{\left(1 - \frac{2}{r^2} + \frac{3}{r^4}\right) \cos 2\theta - \frac{1}{r^2}}$$

where the value of a is taken as unity and ϕ is the angle which the direction of the principal stress makes with the radius

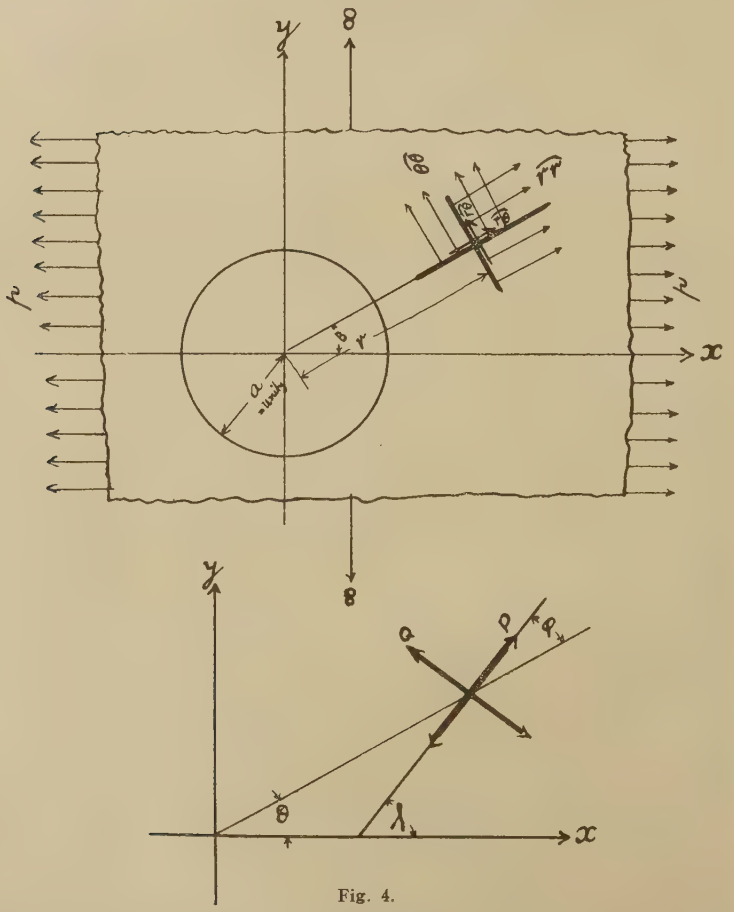


Fig. 4.

vector to a point, Fig. 4. For any given values of θ and ϕ the values of r can be determined by solving a quadratic equation in

Fig. 5.

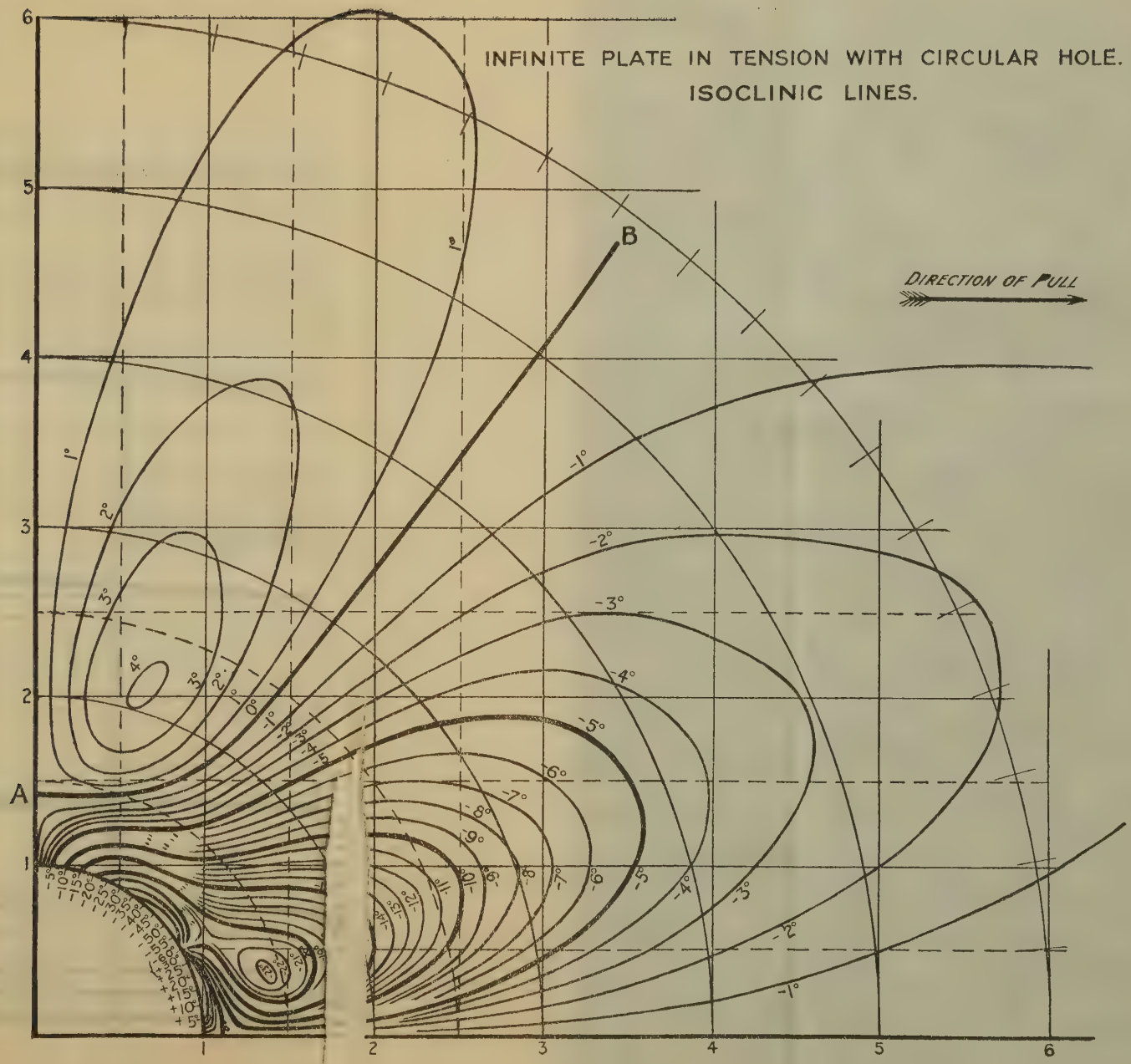

INFINITE PLATE IN TENSION WITH CIRCULAR HOLE.
ISOCLINIC LINES.
DIRECTION OF PULL
A
B
1
2
3
4
5
6

Fig. 7.

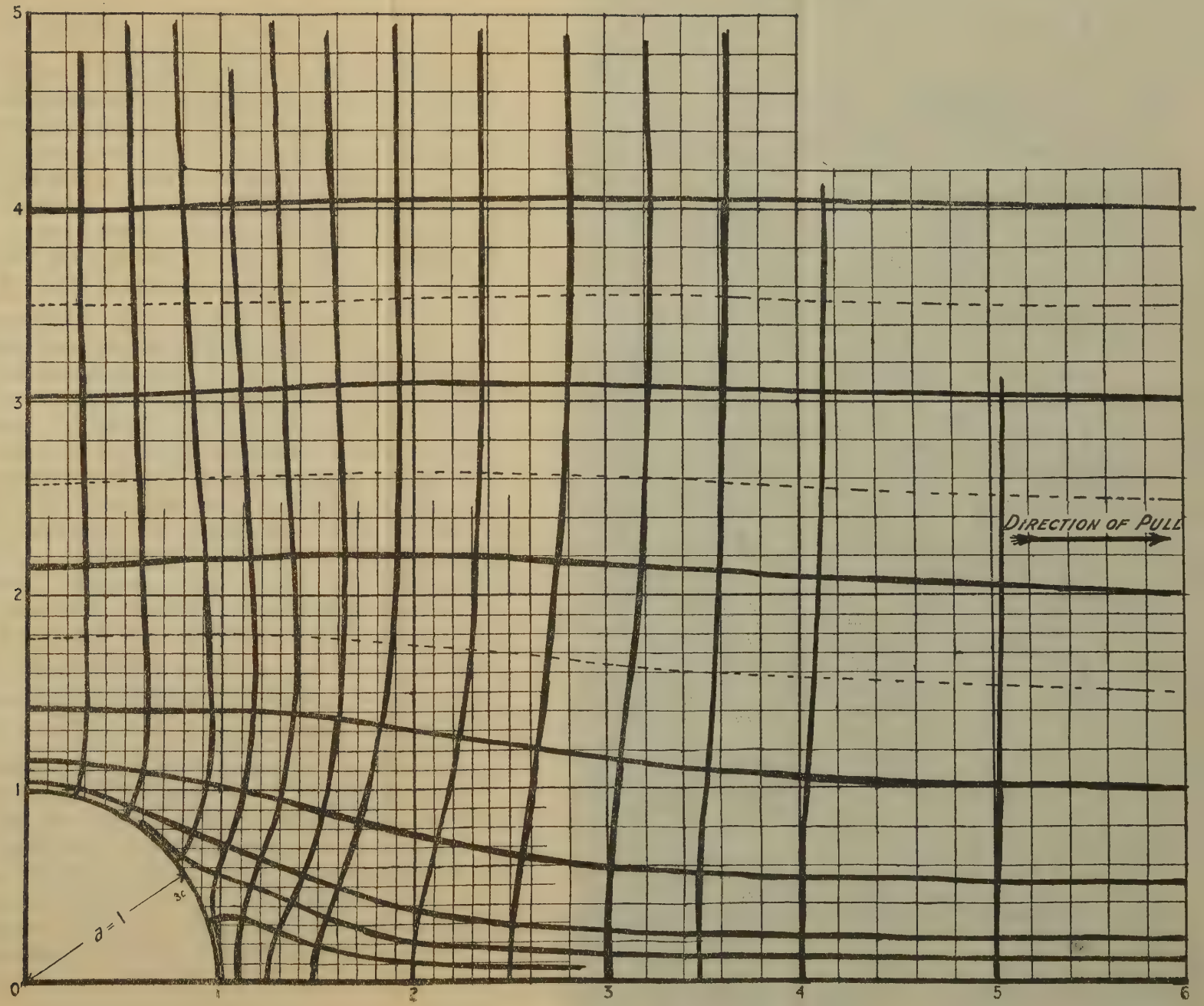
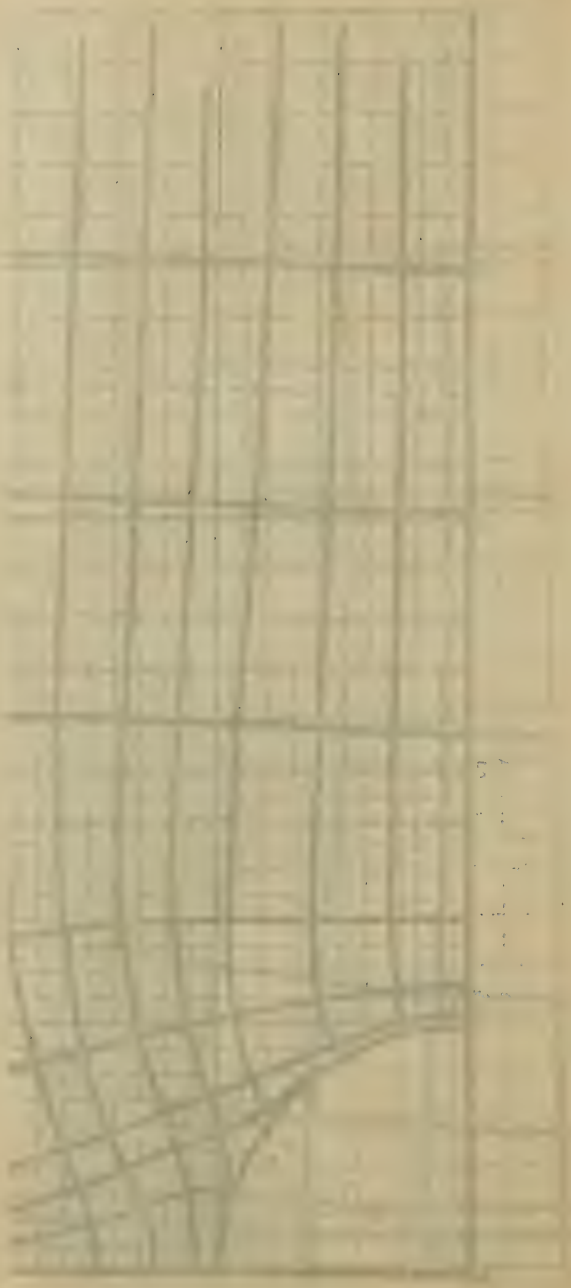


Fig. 8.



$\frac{1}{r^2}$, but the labour involved in calculating a sufficient number of isoclinic lines in this manner is very great, as may be inferred from the fact that if θ and ϕ are varied by increments of 5°, the number of equations to be solved is 17×19 or 323 in all, and a more indirect method of attack is therefore advisable.

For this purpose the values of ϕ may be calculated when r and θ are variables, and if this is performed and the results plotted on a log r base, the values $\lambda = \theta + \phi$ can be readily ascertained for $0 < \theta < \frac{\pi}{2}$, which is sufficient for the purpose, since from symmetry the stress system is repeated in each quadrant. Most of the results of these calculations are plotted in the accompanying Fig. 5, and from the data so obtained it is possible to determine the forms of the curves passing through all points of the plate for which the directions of stress are equally inclined. One of the curves for which $\lambda = \theta + \phi =$ constant is shown in the accompanying diagram, Fig. 6, and a whole series, varying by increments of 1° where necessary, is plotted in Fig. 7 for direct comparison with experimental values. These curves show an interesting peculiarity, as may be observed by inspection. The curve A B divides the quadrantal area into two parts, for which on one side nearly all the lines of principal stress corresponding to the direction normal to pull are inclined at angles of less than $\frac{\pi}{2}$, and on the other at angles greater than $\frac{\pi}{2}$. The area bordering the hole from $0 < \theta < \frac{\pi}{6}$ is, however, an exception. In general, therefore, these curves of principal stress in the longitudinal direction have maximum ordinates at the isoclinic line $\lambda = 0$, if they cut this line, and therefore they approach the axis of pull at all other points within the quadrantal area considered.

The lines of principal stress may be determined fairly accurately by marking their directions at a sufficient number of points along the isoclinic lines, and drawing curves tangential to these directions, commencing from any arbitrary point.

The process may be carried out more accurately by selecting any point (x, y) at which the inclination λ is known, and then determining the position of a neighbouring point $(x+\delta x, y+\delta y)$

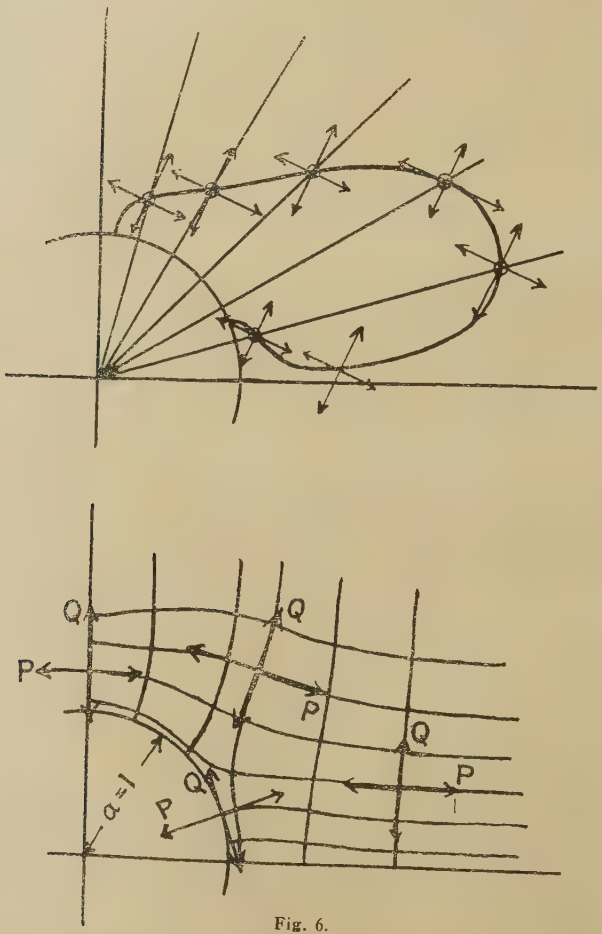


Fig. 6.

by the relation $\delta y = \delta x \tan \lambda$. The limit of accuracy is then conditioned by the smallness of δx and the closeness of the isoclinic curves. This latter process is adopted in the chart, Fig. 8,

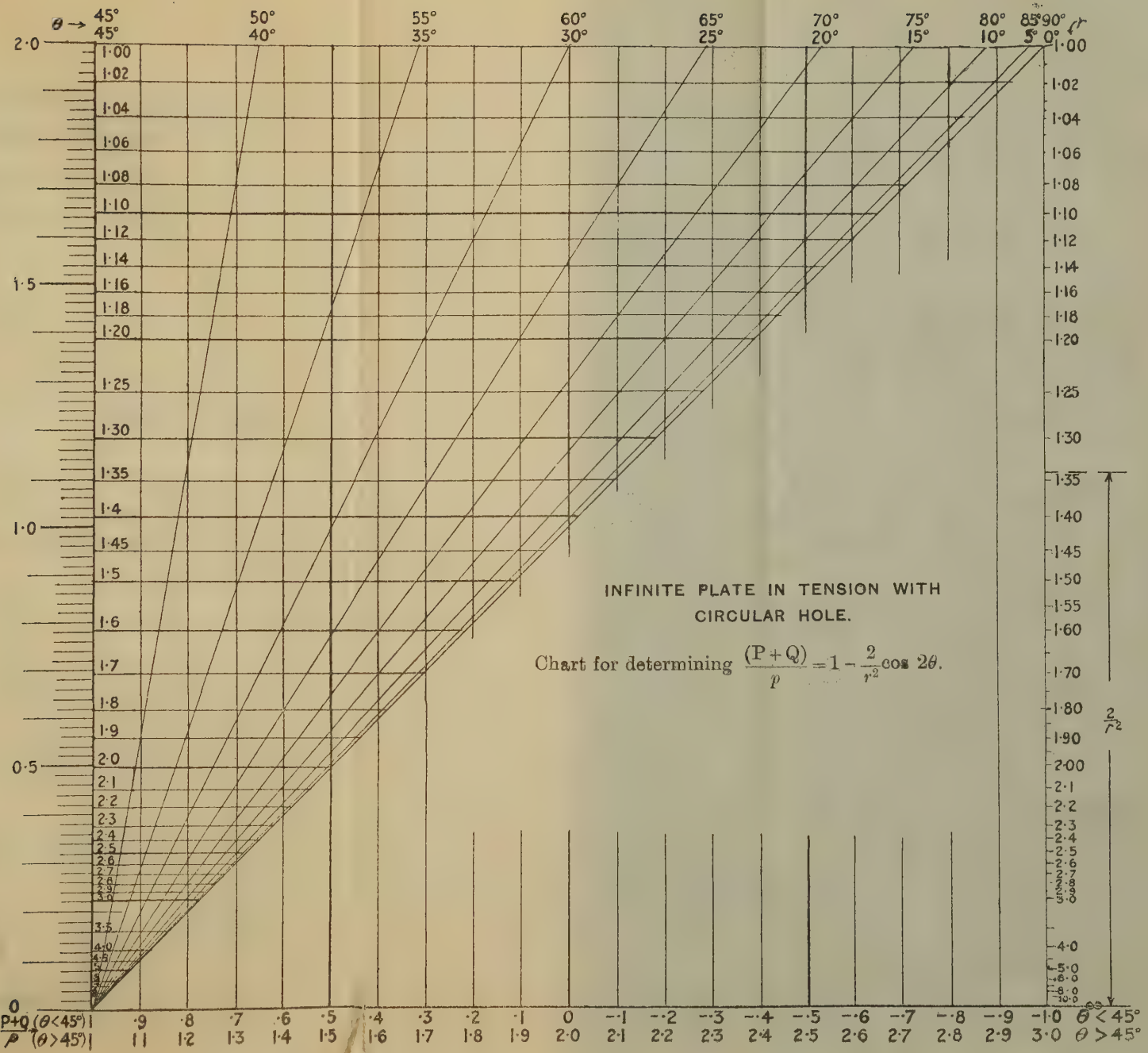

INFINITE PLATE IN TENSION WITH CIRCULAR HOLE.
Chart for determining $\frac{(P+Q)}{p} = 1 - \frac{2}{r^2}\cos 2\theta$.
θ →
45° 45°
50° 40°
55° 35°
60° 30°
65° 25°
70° 20°
75° 15°
80° 10°
85° 5°
90° 0°
r
2·0
1·5
1·0
0·5
0
$\frac{2}{r^2}$
$\frac{P+Q}{p}$ (θ<45°)
(θ>45°)
θ < 45°
θ > 45°

Fig. 10.

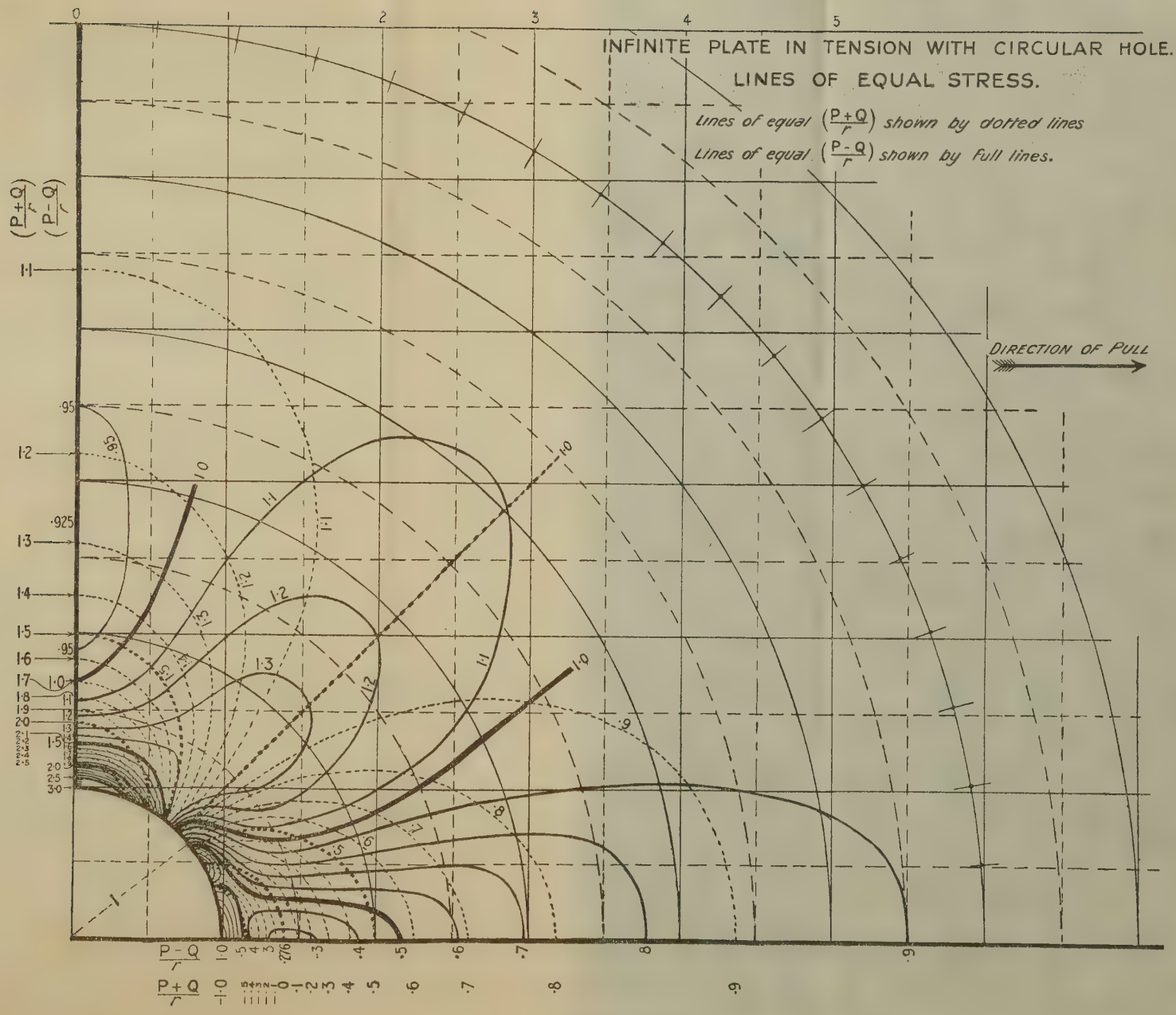

INFINITE PLATE IN TENSION WITH CIRCULAR HOLE.
LINES OF EQUAL STRESS.
Lines of equal $\left(\frac{P+Q}{r}\right)$ shown by dotted lines
Lines of equal $\left(\frac{P-Q}{r}\right)$ shown by full lines.
DIRECTION OF PULL
$\left(\frac{P+Q}{r}\right)$
$\left(\frac{P-Q}{r}\right)$
$\frac{P-Q}{r}$
$\frac{P+Q}{r}$

Fig. 11.

showing the lines of principal stress for a considerable area around a hole in a tension member of infinite width. The values of the principal stresses P, Q, and also P + Q, P − Q, for comparison with observations on finite widths of plate are

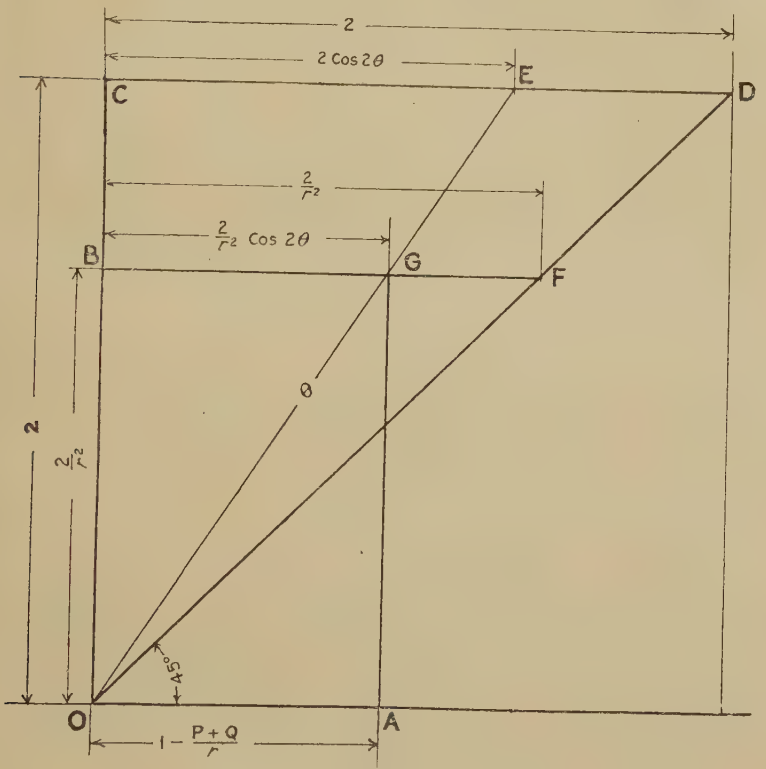


Fig. 9.

directly obtainable from the solution, Appendix A, but they are more readily obtained by a semi-graphical process which it is convenient to describe here.

We have $$P+Q=\widehat{rr}+\widehat{\theta\theta}=p\left(1-\frac{2}{r^2}\cos 2\theta\right)$$

or, $$1-\frac{P+Q}{p}=\frac{2}{r^2}\cos 2\theta,$$

and values of this expression may be readily found graphically by constructing a rectangular chart, Figs. 9 and 10, as follows:—

Take $OC = CD = 2$; $CE = 2 \cos 2\theta$; $OB = \frac{2}{r^2}$, Fig. 9, and draw BGF parallel to CD and intersecting OE in G. Then BG or its projection OA is the value sought. Conversely, if it is required to determine the value of r corresponding to any possible values of $\frac{P+Q}{p}$ and θ, the quantity $1 - \frac{P+Q}{p}$ can be marked off along the horizontal axis and the line $AG = \frac{2}{r^2}$ gives the required value of r. A series of these values are plotted on Fig 11, and are shown by dotted lines.

To determine the value of $P - Q$ the following construction may be adopted, based on the relations,

$$P - Q = \sqrt{(\widehat{rr} - \widehat{\theta\theta})^2 + 4\,\widehat{r\theta}^2}$$

$$\frac{\widehat{rr} - \widehat{\theta\theta}}{p} = \left(1 - \frac{2}{r^2} + \frac{3}{r^4}\right) \cos 2\theta - \frac{1}{r^2} = R \cos 2\theta - \frac{1}{r^2}$$

$$\frac{2\,r\theta}{p} = \left(1 + \frac{2}{r^2} - \frac{3}{r^4}\right) \sin 2\theta = (2 - R) \sin 2\theta$$

where $R = \left(1 - \frac{2}{r^2} + \frac{3}{r^4}\right)$.

On a rectangular chart, Fig. 12, construct a square OABC of 2 units side, and mark off on the side OC, the value $OD = 2 \sin 2\theta$, and on the side AB the value $AE = 2 \overline{\cos 2\theta}$ where the sign ,, denotes that the value of $\cos 2\theta$ is taken with a positive sign. On the side OA mark off $OF = \left(1 - \frac{2}{r^2} + \frac{3}{r^4}\right) = R$; then $AF = (2 - R)$. Draw FLGT parallel to OC, intersecting AD in L, OE in G, and OB in T, and project L and G on to the side OC, giving intercepts X and V.

Then $FG = OV = R \overline{\cos 2\theta}$, and

$$FL = OX = (2 - R) \sin 2\theta = \frac{2\,\widehat{r\theta}}{p},$$

also $VS = OV = R \overline{\cos 2\theta}$.

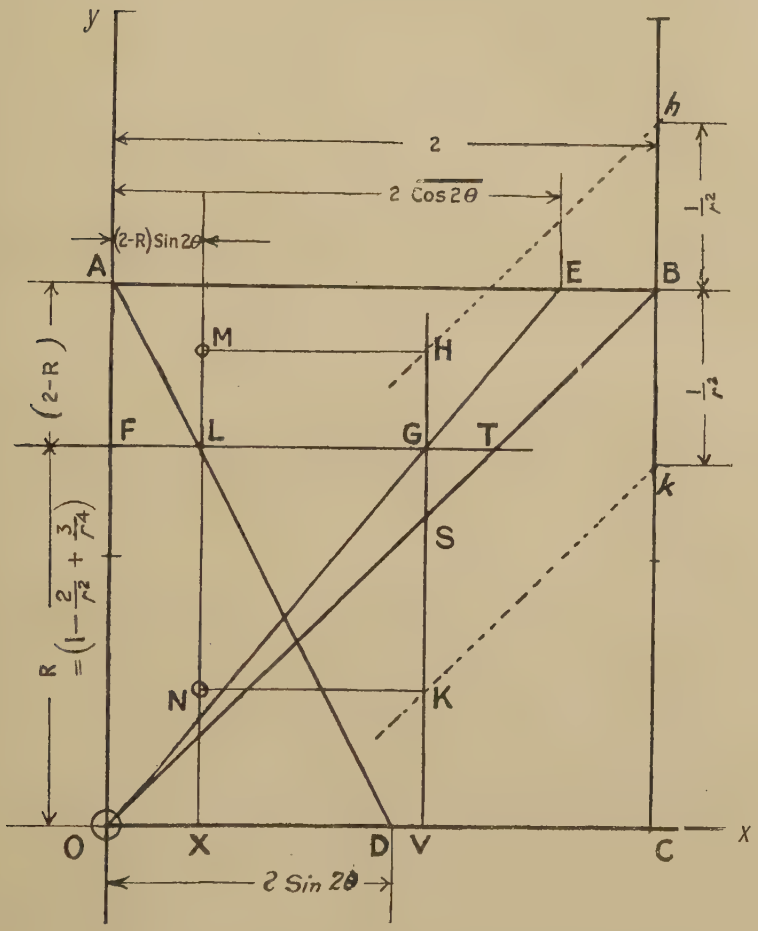

y
h
2
2 Cos 2θ
(2-R) Sin 2θ
A
E
B
M
H
(2-R)
F
L
G
T
k
S
R = (1 − 2/r² + 3/r⁴)
N
K
O
X
D
V
C
x
2 Sin 2θ

Fig. 12.

Mark off on the vertical through B the values $Bh = Bk = \frac{1}{r^2}$, and draw parallels to OB through the points h, k to intersect the vertical through G in H and K. Project these latter points on to the vertical through L to give the intersections M and N, then

$$VH = VS + SH = R\overline{\cos 2\theta} + \frac{1}{r^2}$$

$$VK = VS - SK = R\overline{\cos 2\theta} - \frac{1}{r^2}.$$

Now if $\theta < 45°$, cos 2θ has a positive value and $\frac{\widehat{rr} - \widehat{\theta\theta}}{p} = VK$.

If $\theta > 45°$, cos 2θ is negative and $\frac{\widehat{rr} - \widehat{\theta\theta}}{p} = -VH$.

$$\therefore OM = \sqrt{OX^2 + XM^2} = \sqrt{OX^2 + VH^2} = \frac{1}{p}\sqrt{\overline{(\widehat{rr} - \widehat{\theta\theta})^2 + 4\cdot\widehat{r\theta}^2}} = \frac{P - Q}{p},$$

if $\theta > 45°$, and

$$ON = \sqrt{OX^2 + XN^2} = \sqrt{OX^2 + VK^2} = \frac{1}{p}\sqrt{\overline{(\widehat{rr} - \widehat{\theta\theta})^2 + 4\cdot\widehat{r\theta}^2}} = \frac{P - Q}{p},$$

if $\theta < 45°$

for the given values of r and θ.

The reverse process of determining r, θ from any point M is difficult. It is therefore necessary to construct a chart from which the values of r can be read off.

This may be carried out in the following way. Draw a series of lines hH, kK corresponding to given values of r, and mark off on the appropriate axis a corresponding set of values of $R = f(r)$. Also determine a series of points D and E for given values of θ. Then for a definite value of r, and varying values of θ, a series of curves on which the points M lie can be found, Fig. 13. Similarly if θ is fixed and r is varied a second set of curves may be constructed intersecting the first set. With these two systems it is possible to read off values of r, θ corresponding to any given values of $\frac{P - Q}{p}$ or *vice versa*. The full series of curves used in constructing the diagrams described is

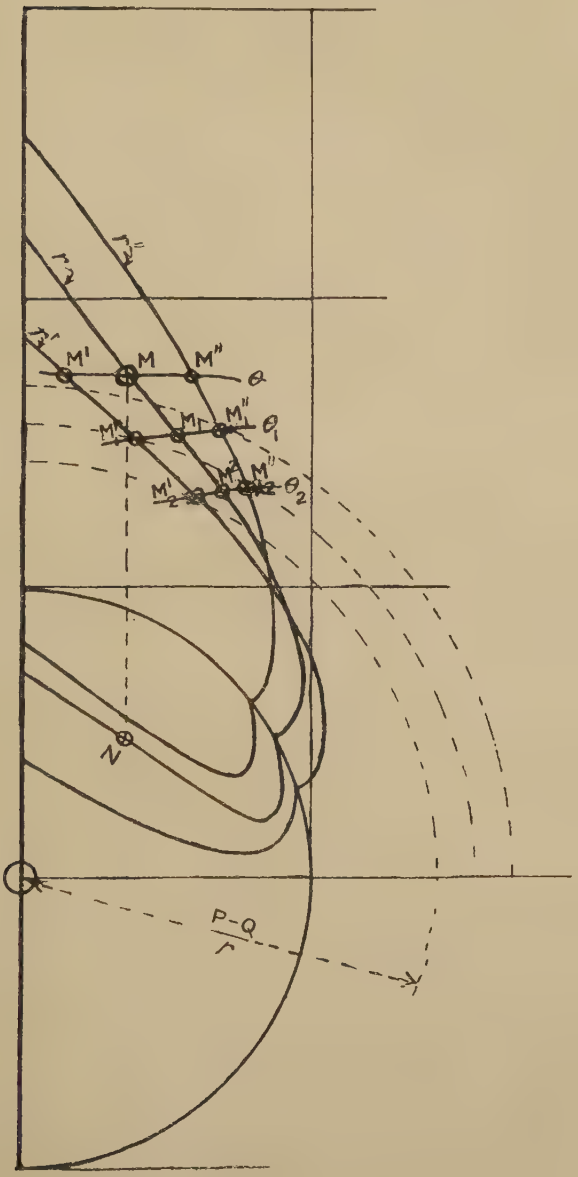


Fig. 13.

too complicated to be reproduced here, but from such a chart curves of constant $\frac{P-Q}{p}$ have been constructed by increments of 0·1 through the whole range of stress. These latter curves are shown in Fig. 11, in which full lines denote $\frac{P-Q}{p}$ and dotted lines $\frac{P+Q}{p}$. The former correspond to the isochromatic lines given in the polariscope, and may therefore be used for comparison with the stress in plates of finite width.

It may also be noted that from this form of chart the value of 2ϕ can be found, and therefore the isoclinic lines can be drawn. This is at once seen from the relation

$$\tan \mathrm{M\hat{O}}y = \frac{\mathrm{OX}}{\mathrm{MX}} = \frac{2 \cdot \widehat{r\theta}}{\widehat{rr} - \widehat{\theta\theta}} = \tan 2\phi$$

showing that the angle which OM makes with the vertical axis is $\pm 2\phi$. The sign is easily chosen for any given point. It is also important to note that from the curves of equal $\frac{P+Q}{p}$ and $\frac{P-Q}{p}$ the curves of equal $\frac{P}{p}$ and $\frac{Q}{p}$ can be readily determined. Thus, for example, if curves of $P+Q$ corresponding to constant values $(2m)$ are known, and a similar set for $P-Q$ corresponding to $(2n)$, then the points of intersection of the series obtained, by giving various values to M and N, correspond to

$$P = m + n$$
$$Q = m - n$$

as Fig. 14 indicates.

The form of the curves for $\frac{P-Q}{p}$ = a constant, Fig. 11, shows that along a line parallel to the axis of pull and a finite distance away the value of $\frac{P-Q}{p}$ reaches a minimum at its intersection with the minimum section, and also passes through a region of higher value as it proceeds outwards.

This confirms the qualitative observations on finite plates. The range of this stress variation may be determined by two independent methods, namely, by photo-elastic measurements of

P − Q, or by mechanical measurements of P + Q, since these coincide along a boundary under no applied force. Both forms of measurement are given in Fig. 15a in the case of a tension

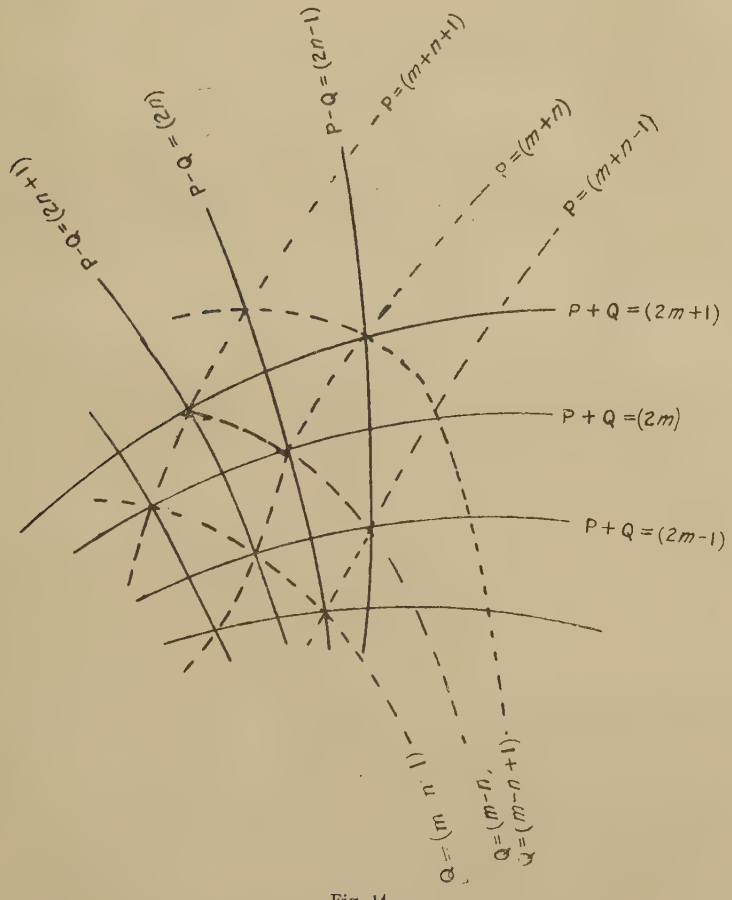


Fig. 14.

member 0·992 inch × 0·1812 inch in cross section, to which a load of 100 lbs. is applied, giving a mean value of the stress of 556 lbs. per square inch at the full section and 1,112 lbs. per

square inch at the minimum section produced by boring a central hole of $\frac{1}{2}$ inch in diameter. The values of the stresses obtained are also shown by the accompanying measurements, Table I, from which it appears that at a distance from the minimum section corresponding to the half breadth the stress reaches a maximum of about 800 lbs. per square inch, while at the centre, although the mean average stress is 1,112 lbs. per square inch, the actual stress is not more than 600 lbs. per square inch, owing to the great concentration of the stress distribution at the inner circular boundary. Although both sets of measurements are not quite identical, and the symmetry is not perfect, their substantial agreement is evident, and taken with the evidence afforded by the disposition of the isochromatic lines they show very conclusively that diminution of the section is accompanied by diminution of stress at this point of the minimum cross section, a somewhat unexpected result, and one not likely to be predicted from general considerations. The stress distribution around the interior contour also varies widely, and in fact has a very large tensional value at the end points of the diameter perpendicular to the line of pull, which gradually diminishes until at an angular distance of somewhat less than 60° it vanishes and changes to compression with a maximum value at the ends of a diameter coincident with the axis.

These values are recorded in Table I, and are also plotted in Fig. 15b, together with corresponding values shown by dotted lines for a pull stress corresponding to this width of plate obtained by an approximate calculation, Appendix B. It is worthy of note that the measured values are somewhat less than the values so calculated, although the difference is not large, and tends to diminish with the size of the hole.

The curve of stress distribution across the minimum section is readily obtained by a combination of the methods mentioned above; and as appears from the measurements, Table I, the maximum stress is at the edge of the hole, and almost exactly $3p$ where p is defined as above.

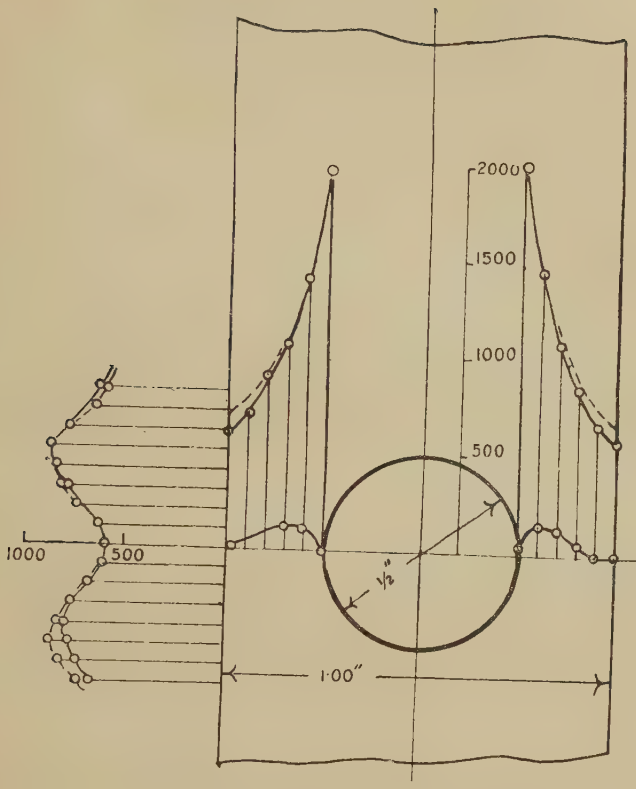


Fig. 15a

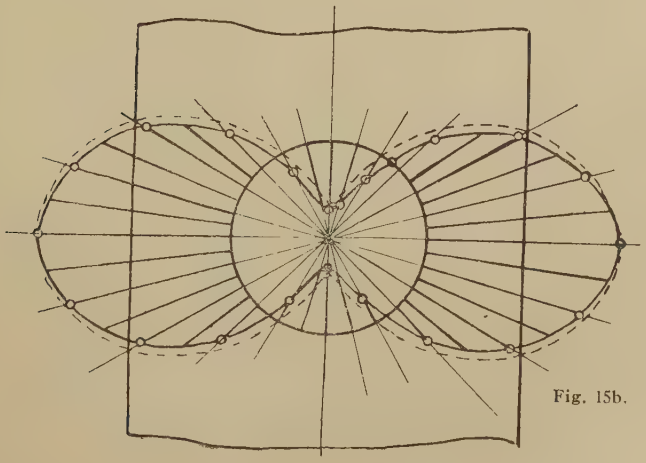


Fig. 15b.

TABLE I.

½″ Diameter Hole.				
x	$p+q$	$p-q$	p	q
−·50	590	600	595	−5
−·45	700	690	695	+5
−·40	890	880	895	+5
−·35	1,170	950	1,060	110
−·30	1,500	1,300	1,400	100
−·25	—	1,960	1,960	0
0	—	—	—	—
+·25	2,050	2,000	2,025	25
+·30	1,630	1,320	1,475	155
+·35	1,230	960	1,095	135
+·40	900	830	865	35
+·45	640	690	615	−25
+·50	600	—	600	—

½″ Diameter Hole.		
y	$p+q$	$p-q$
·7	670	650
·6	770	790
·5	840	880
·4	800	850
·3	800	830
·2	740	—
·1	580	620
0	590	600
−·1	640	620
−·2	620	660
−·3	780	760
−·4	800	820
−·5	770	830
−·6	720	820
−·7	660	730

½″ Diameter Hole.		Calculated Value $p=652$
θ	$p-q$	
0	1,960	1,955
15°	1,800	1,780
30°	1,190	1,315
45°	490	650
60°	−280	0
75°	−600	−480
90°	−700	−650

The curve of variations, however, falls somewhat faster than for the case of an infinite plate, as the dotted lines for this case show. The cross stress is, moreover, insignificant, and rises to its maximum value at a radius of about 1.2r to 1.4r, with zero values at each end. The measurements confirm the theory that such stresses are small, and may be neglected except when considerable accuracy is required. If the size of the hole is diminished while the width of the tension member remains the same, the effects produced show the same general characteristics. They have been measured for holes ⅜ inch and ¼ inch diameter respectively, and the values are recorded in the accompanying Tables II and III, and are plotted in Figs. 16a, 16b, 17a, and 17b.

Along the parallel sides the maximum stresses, already noted, tend to approach to the minimum at the central section, and the inequalities of stress distribution also decrease with the radius of the hole; in fact, with a small hole of ¼ inch diameter the difference of stress along the external contours is too small to measure with certainty, and for all practical purposes may be neglected.

On the other hand, the stress variation around the inner contour differs very little from the variations shown to exist in the larger hole, and, moreover, conforms very closely to approximate calculations for the stress distribution. This is apparent in Fig. 17b and Table III, where both curves are very close together, but still with measured values of slightly less magnitude than those calculated by the formula. The points of zero stress are, moreover, at angular distances of less than 60° from the diameter perpendicular to the line of pull. With the smaller hole, however, Fig. 17b, the two curves practically coincide throughout, and the points of zero stress occur in the positions agreeing with calculations for an infinite width of plate. It may also be observed that the maximum stress is still very approximately 3r.

The cross stresses also show variations which follow the law

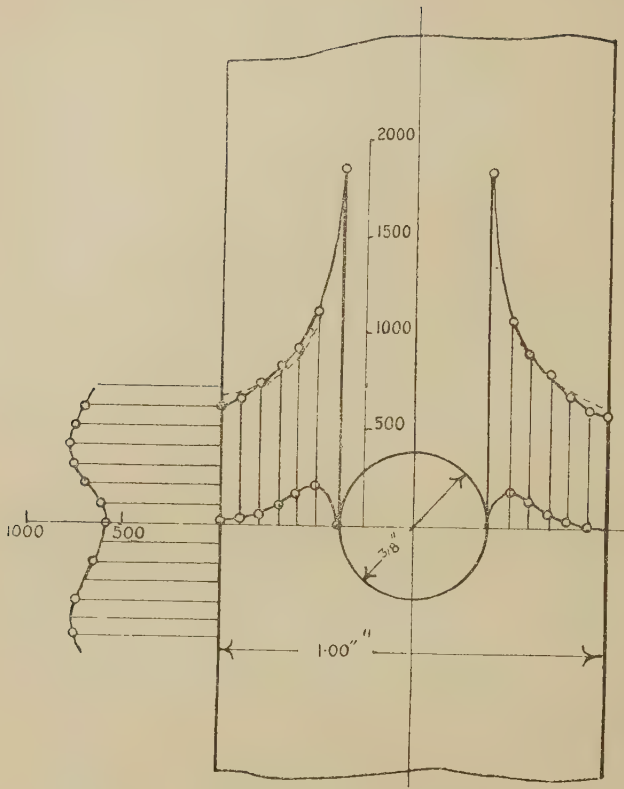


Fig. 16a.

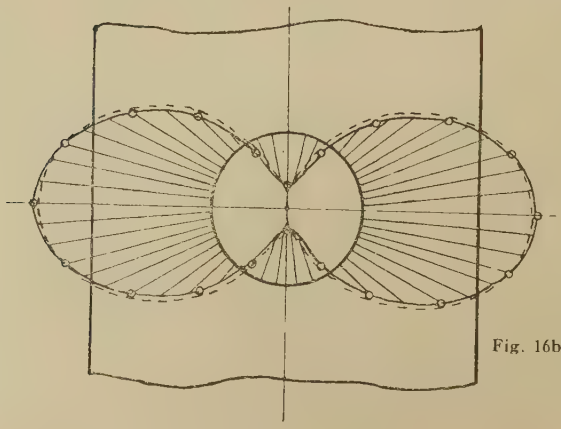


Fig. 16b.

Table II.

⅜″ Diameter Hole.				
x	$p+q$	$p-q$	p	q
—·50	610	570	590	20
—·45	660	600	630	30
—·40	760	660	710	50
—·35	910	710	810	100
—·30	1,070	760	915	155
—·25	1,300	900	1,100	200
—·19	—	1,860	1,860	—
0	—	—	—	—
·19	—	1,830	1,830	—
·25	1,260	890	1,075	185
·30	1,050	760	905	145
·35	870	730	800	70
·40	700	660	680	20
·45	610	600	605	5
·50	590	—	590	—

⅜″ Diameter Hole.	
x	$p-q$
·6	700
·5	780
·4	790
·3	770
·2	700
·1	610
0	570
—·1	—
—·2	650
—·3	710
—·4	740
—·5	—
—·6	740

⅜″ Diameter Hole.		Calculated Value.
θ	$p-q$	$p=598$
0	1,830	1,795
15°	1,600	1,635
30°	1,200	1,195
45°	610	600
60°	—120	0
75°	—450	—440
90°	—580	—600

for $\widehat{rr}$, Appendix A, with maxima which tend towards the position $r = a\sqrt{2}$, as indicated by the theory, as the holes decrease in size relatively to the width of the plate. As their

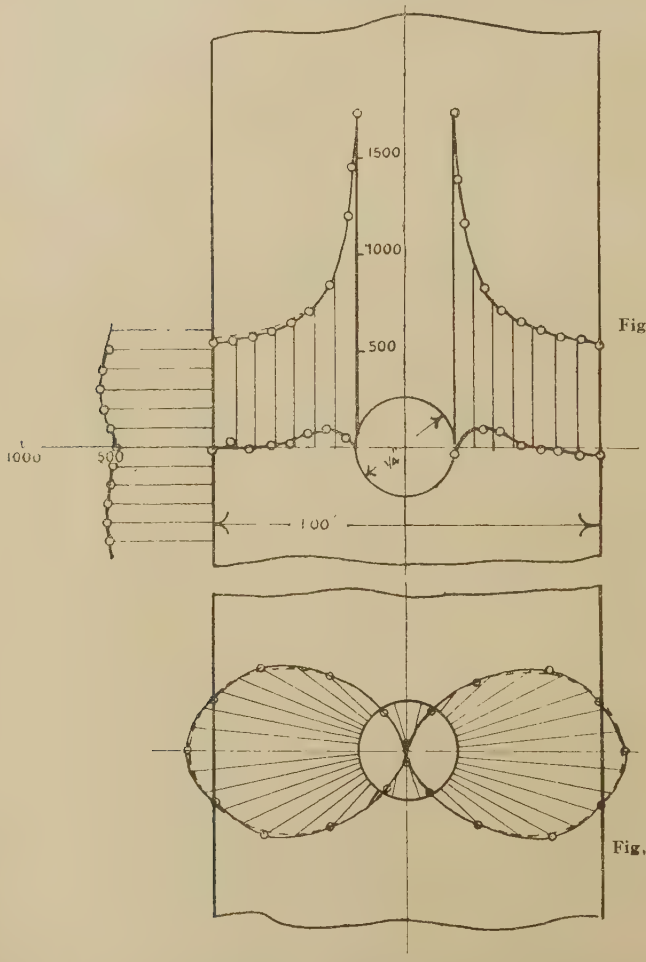


Fig. 17a.

Fig. 17b.

values are obtained by the difference of two sets of measurements, it is not surprising that they do not agree so well with the theoretical expressions as do the values of $\widehat{\theta\theta}$, for any errors

Table III.

¼″ Diameter Hole.				
x	$p+q$	$p-q$	p	q
—·50	530	540	535	— 5
—·45	535	510	525	13
—·40	550	580	565	—15
—·35	600	—	600	—
—·30	650	630	640	10
—·25	760	630	700	65
—·20	930	750	840	90
—·15	1,240	1,160	1,200	40
—·14	1,440	1,460	1,050	—10
—·125	—	1,720	1,720	—
0	—	—	—	—
·125	—	1,730	1,730	—
+·14	1,350	1,400	1,375	—25
+·15	1,160	—	1,160	—
·20	910	760	885	75
·25	790	640	715	75
·30	660	660	660	—
·35	610	630	620	—15
·40	560	580	570	—10
·45	530	600	565	—35
·50	500	560	580	—30

¼″ Diameter Hole.	
y	$p-q$
·5	520
·4	550
·3	—
·2	500
·1	490
0	490
—·1	500
—·2	510
—·3	520
—·4	540
—·5	520
—·6	500

¼″ Diameter Hole.		Calculated Value.
θ	$p-q$	$p=569$
0	1,720	1,710
15°	1,530	1,555
30°	1,200	1,140
45°	580	570
60°	—20	0
75°	—400	—420
90°	—540	—570

of measurement tend in general to accumulate in the values of $\widehat{rr}$ and to become a considerable percentage of the true value.

It is perhaps worthy of note that a practical rule may be derived from the measurements whereby the maximum stress can be determined in terms of the mean stress at the minimum section and the ratio c of the width of the plate to the diameter of the perforation. This may be stated in the form

$$p_{\max} = \frac{3c}{c+1} p_{\text{mean}}$$

and is derived in Appendix B.

It will be found in general to give fair values unless the hole is relatively large compared with the width of the plate.

It is worth while examining the case of a very large hole in a tension member, because it might possibly be thought that, for such a case, the stress distribution at the minimum section tends to become uniform. It is apparently taken to be approximately so by at least one authority,* but experiment does not confirm this view, as variation in stress distribution at the minimum section is still very great when the diameter of the hole approaches the width of the plate. A case of this kind is shown in the accompanying Fig. 18, in which a hole of ·88 inch diameter is bored in a plate 1·1 inches wide. The stress distributions recorded there and in Table IV show that the relative variation of tension across the section of minimum area is greater than in any of the preceding cases, and when the hole is increased in size still further there is a maximum tension at the inner boundary, which may possibly pass through a zero value as we proceed outwards, and become a compression stress at the outer parallel sides.

The danger of fracture at the inner boundary is therefore much increased in such a case if an estimate of the probable maximum stress is derived from average values obtained by

* Dr. A. Leon—"Kerbgrösse und Kerbwirkung," Plate 3, Fig. 25. No. 10, Mitteilung aus dem Mechanisch-Technischen, Laboratorium der K. K. Technischen Hochschule in Wien.

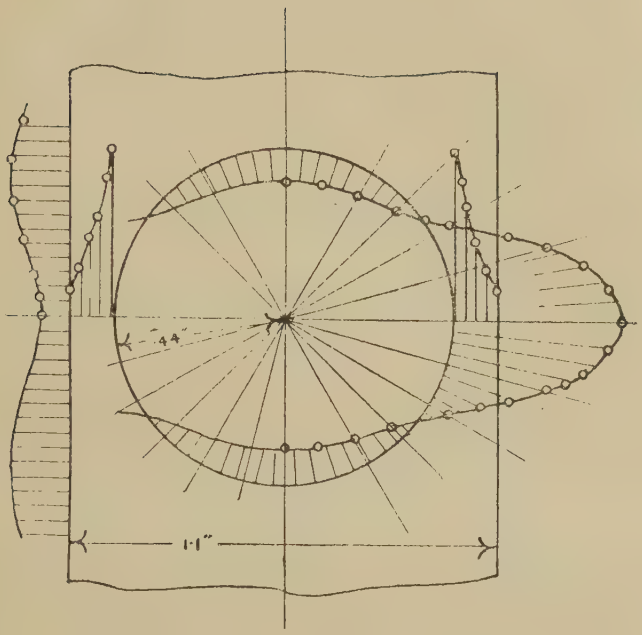


Fig. 18.

TABLE IV.

0·88″ Hole Width = 1·1″	
$y=0$ $x=$	$p-q$
·44	1,730
·46	1,440
·48	1,010
·50	840
·52	500
·55	270

0·88″ Hole Width = 1·1″	
$x=$ 1·1″ $y=$	$p-q$
0	270
·05	300
·10	400
·20	670
·30	800
·40	800
·50	680

0·88″ Hole Width = 1·1″	
θ	$p-q$
0	1,730
5	1,600
10°	1,420
15°	1,080
20°	720
25°	450
30°	220
36°	0
45°	−260
60°	−280
75°	−340
90°	−360

dividing the total load by the area of the minimum cross section, and it is clear that the approximate formula given above is no longer applicable.

In the present example, however, tension is preserved throughout, and it is, moreover, to be observed that the maximum values along the straight boundaries are about three times the value at the central section, and are separated by a considerable interval. Around the periphery of the hole there is now much

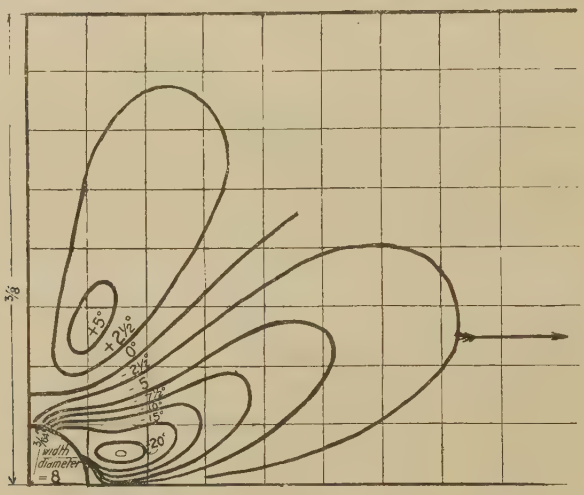


Fig. 19a.

more tangential compression stress, while the zero value is at an angular distance of about 35°.

If such cases are important in practice it might be worth while to consider them in more detail, but it is not possible to make more than a passing reference here, to call attention to the distinctive features observed, and to show their general tendency.

Isoclinic Lines.

The isoclinic lines found in the cases cited above also afford some information of value, as may be observed from Figs. 19a to d, of observations made on a tension member $\frac{3}{4}$ inch wide, and

OPTICAL DETERMINATION OF

ISOCLINIC LINES OF PARALLEL TENSION MEMBERS WITH CIRCULAR HOLES

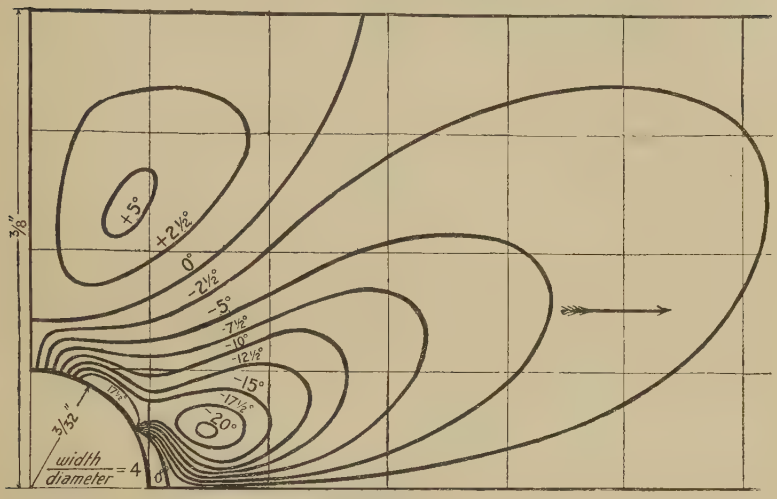


Fig. 19b.

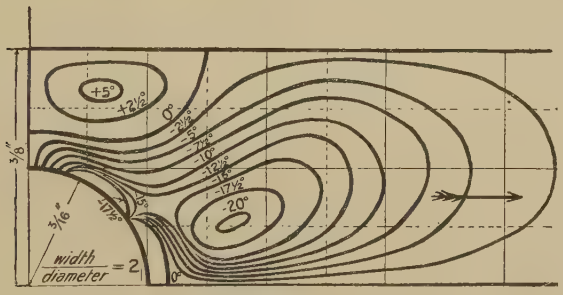


Fig. 19c.

Fig. 19d.

with centrally-placed holes having a ratio of width to diameter varying from 8 to $1\frac{1}{2}$. The principal line $\lambda = 0°$ indicates the points where one set of lines of principal stress intersecting $\lambda = 0°$ attains a maximum ordinate with reference to the axis, while the other isoclinic lines indicate that there is a gradual movement of the stress lines towards the axis even when the plate approaches an infinite width. This double curvature in the lines of principal stress running more or less axially is shown in earlier papers. Other lines also intersect an isoclinic $\lambda = 0°$ at the crown of the hole, and some of these pass around the aperture, but those nearest the centre line terminate abruptly at the contour, as Fig. 8 shows. The point of zero stress around the contour also moves away from the position $\theta = 30°$, and its angular distance from the axis increases with the diameter of the hole. The curves also enable an estimate to be formed of the extent of the disturbance from uniform stress conditions, since it is clear that there must be some finite distance at which non-uniform stress becomes negligible.

Both the isoclinic and isochromatic bands corresponding to this condition are, however, so broad and ill-defined that for accurate work it is necessary to measure the stress distribution over a considerable area, but an approximate distance can be obtained by taking a curve $\lambda = \alpha$ where α is selected arbitrarily provided it is small. The value α in the present examples has been taken as 2·5 degrees, and it is then found that the maximum distance corresponding to each size of hole tested is as shown in the accompanying table:—

TABLE V.

Diameter of Hole (inches)	$\frac{3}{32}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{1}{2}$
Maximum distance (inches) from the minimum section of the isoclinic curve $\lambda = 2{\cdot}5°$ - -	0·34	0·58	0·83	1·00

Tension member $\frac{3}{4}$ inch × ·1213 inch.

These values are plotted on the accompanying Fig. 20 to enable intermediate values to be determined, as the curve there represented does not appear to follow a simple algebraic law.

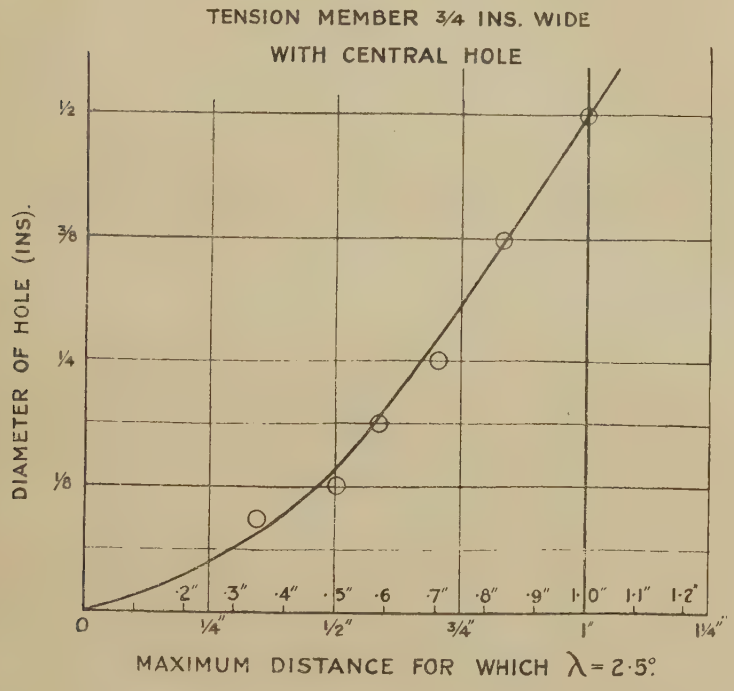

TENSION MEMBER ¾ INS. WIDE
WITH CENTRAL HOLE
DIAMETER OF HOLE (INS).
½
⅜
¼
⅛
·2″ ·3″ ·4″ ·5″ ·6 ·7″ ·8″ ·9″ 1·0″ 1·1″ 1·2″
0 ¼″ ½″ ¾″ 1″ 1¼″
MAXIMUM DISTANCE FOR WHICH λ = 2·5°

Fig. 20.

Comparison of Stress Distribution in Perforated Steel and Nitro-Cellulose Tension Members.

The measurement of the stress distribution in a metal tension member having discontinuities involves very accurate observations of minute lateral strains, and a true measure of the sum of the principal stresses is therefore difficult to obtain, while the difference values cannot be obtained optically. We have

therefore been content to measure this sum at various points, in order to show that these values agree with those obtained from optical material. The mean strain ϵ_{zz} in the direction of the thickness of a plate stressed in its own plane has a value given by the equation

$$m\ \mathrm{E}.\epsilon_{zz} = -(p+q) \quad - \quad - \quad - \quad (1)$$

where m is Poisson's ratio, E is Young's modulus and $(p+q)$ is the sum of the principal stresses with reference to the line along which ϵ_{zz} is measured. The quantities m and E do not change very much with different specimens of the same material, and are usually in the neighbourhood of 2·5 and 300,000 for nitro-cellulose, and 3·5 and 30,000,000 for steel, the units being pounds and inches.

In order to avoid exceeding the elastic limit of nitro-cellulose, it is advisable not to exert a stress of more than about 1,500 pounds per square inch, while for clearness of optical effect the thickness should not be more than $\frac{1}{4}$ inch.

In the present examples this thickness is ·18 inch approximately, and the maximum lateral strain at the limiting stress is $-$·002 inch, corresponding to a lateral change of ·00036 inch. For an accuracy of 2 per cent. the extensometer must therefore be capable of measuring to an accuracy of seven millionths of an inch. This is not difficult if temperature conditions are quite uniform, but for metals the conditions are more exacting, for although the stresses may be much greater without exceeding the elastic limit, the high value of E makes the lateral strain exceedingly small, thus for $(p+q) = 10{,}000$ pounds per square inch, the strain is $-\frac{1}{10{,}500}$ inch, and the lateral change for a thickness of 0·5 inch is therefore $\frac{1}{21{,}000}$ inch, or slightly less than five one hundred thousandths of an inch. If the same standard of accuracy is adopted as for nitro-cellulose, the extensometer must be capable of reading to an accuracy of about one millionth of an inch. It is therefore probable that in any comparison between nitro-cellulose and steel the

measurements on the former are likely to be more accurate than for the latter.

In order to demonstrate that there must be agreement between results obtained from these different materials, it is probably sufficient to rely upon the fact that, on the usual assumptions of elastic theory, the fundamental stress equations contain no elastic constants.

Although no experiments have been made especially to prove that this agreement does exist here, it happens that the information for testing its substantial accuracy is available in the form of laboratory records made by a former Japanese research student, the late Y. Satake, who devoted a large amount of time and care during the session of 1914-15 to an investigation of the stress distribution in metal plates both below and above the yield stress.

In one of these experiments a steel bar was well annealed to remove initial stresses, and its physical constants determined in the usual manner. A specimen, 1·5 inch broad and 0·488 inch thick, showed a yield stress of 40,600 pounds per square inch, while the greatest stress it sustained before local contraction commenced was 57,000 pounds per square inch, and the total elongation at fracture was 23·4 per cent. on a gauge length of 8 inches.

The modulus of direct elasticity E proved to be $30{\cdot}25 \times 10^6$ in inch-pound units, with a value of m of 3·25.

A similar specimen was prepared by drilling a central hole $\frac{1}{2}$ inch in diameter therein, and the lateral contraction at various points was measured under a simple tension load applied at a considerable distance from the discontinuity.

The strain readings recorded across the minimum section are shown in the accompanying Table VI for a load of 2·8 tons, corresponding to a mean stress of 12,850 pounds per square inch across the minimum section, and their stress equivalents are obtained from the equation (1) above, using the values of the constants already found from a simple tension experiment.

TABLE VI.

Distance from Centre of Hole. Ins.	Lateral Strain $\div 10^{-6}$	$(p+q_1) = mE\epsilon_{zz}$ $= 98{\cdot}3\times$ Lateral Strain.
·256	232	22,800
·266	227	22,310
·320	205	20,150
·376	179	17,600
·476	147	14,450
·576	114	11,210
·676	105	10,320
·710	92	9,040

Mean stress at central section $= \dfrac{2{\cdot}8 \times 2240}{{\cdot}488 \times 1{\cdot}00} = 12{,}850$ lbs. per square inch.

$$p_m = p\left(1+\frac{1}{c}+\frac{1}{2c^2}+\frac{1}{2c^3}\right) \text{ where } c=3$$
$$= p\frac{38}{27} \text{ giving } p = 9{,}137 \text{ lbs. per square inch.}$$

The equivalent tension for a plate of infinite width is readily found from equation 9, Appendix B, and by aid of Table VII the corresponding theoretical stress curve is determined, subject to the obvious correction that the cross radial stress $\widehat{rr}$ must vanish at the outer contour, thereby giving $\widehat{\theta\theta}$ as 9,815 pounds per square inch when $r = 3a$.

There are no experimental values on a plate of optical material which correspond exactly to this case, but those made with a $\frac{3}{8}$-inch hole in a plate 1 inch wide give nearly the right proportions, except as regards thickness, but this dimension is not material, since all stresses and strains are averages in this direction.

For comparison purposes, the linear dimensions of the nitro-cellulose specimen are increased to make the holes agree in size, while the stresses are adjusted in the ratio of their equivalent tensions, page 77, equation 9, Appendix B. The numerical values are recorded in Tables VII and VIII, and are plotted

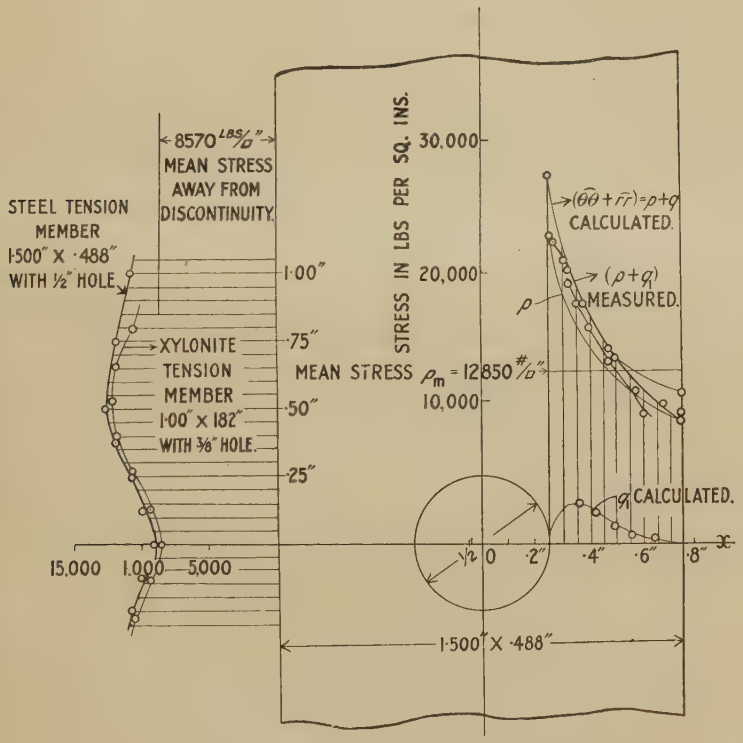


Fig. 21

on Fig. 21. As will be observed, the agreement of all these curves is a remarkably close one, and the only serious difference occurs at the highest values for the steel tension member, where the curve of stress distribution bends over somewhat, in a way characteristic of overstressed material.

Table VII.

Tension Stress across Minimum Section of Xylonite Tension Member 1·00″ × 0·182″ with Central Hole ⅜″ Diameter.								Remarks.
x (ins.)	·19	·25	·30	·35	·40	·45	·50	
$(p+q)$ lbs./sq. in.	—	1,260	1,050	870	700	610	590	Right side.
	—	1,300	1,070	910	760	660	610	Left side.
Steel Tension Member.								
x_1 (ins.)	·253	·33	·40	·47	·53	·60	·63	
$(p_1+q_1)=15{\cdot}28\,(p+q)$	—	19,250	15,940	13,300	10,700	9,320	9,015	Right side.
	—	19,860	16,350	14,000	11,610	10,090	9,320	Left side.

$=98.$	$r=a.$	$r=1{\cdot}25a$	$r=1{\cdot}5a.$	$r=2a.$	$r=3a.$
$\widehat{\theta\theta}/p$	3	1·934	1·519	1·219	1·074
$\widehat{rr}/p$	0	·346	·370	·281	·148
$\dfrac{\widehat{\theta\theta}+\widehat{rr}}{p}$	3	2·280	1·889	1·500	1·222
$(\widehat{\theta\theta}+\widehat{rr})$ For $p=9{,}137.$	27,410	20,830	17,260	13,710	11,170
				$\widehat{\theta\theta}$ = 9,815	

Table VIII.

Cross Stress Data obtained from a Xylonite Tension Member 1·00″×0·182″ with Central Hole r=·1875.

x (ins.)	·19	·25	·30	·35	·40	·45
$\frac{r}{a}$	1·086	1·43	1·71	2·00	2·29	2·57
Mean q lbs./sq. in.	—	193	150	85	35	18
Steel Tension Member.						
$q_1=\frac{9{,}137q}{598}$ $=15{\cdot}28\,q$	—	2,950	2,290	1,310	535	275

Area under curve $p=5{\cdot}14+{\cdot}78-{\cdot}520=5{\cdot}32$ sq. in.

Area under line $p_m=5{\cdot}14$ sq. in.

Average error in measurement of $p=3{\cdot}5$ per cent.

Strain Measurements on Straight Contours.		
$x=-{\cdot}75''$ y (ins.)	Lateral Strain $\div 10^{-6}$	p $=mE\epsilon_{zz}$ $=98{\cdot}3\times$ Lateral Strain.
0	92·0	9,040
·125	102·0	10,020
·250	109·0	10,070
·375	122·0	11,990
·500	128·0	12,580
·750	121·0	11,890
1·000	110·0	10,810

Any error here is, however, probably due to an incorrect measurement of the exact position of the measuring needles with reference to the edge of the hole. The optical readings are somewhat higher than the theoretical value, but are not subject to this type of error.

It will be noticed, however, that the observed stress is rather higher than the limits which are stated to be desirable. Recent experiments, however, now in course of publication, appear to show that the linear law of stress optical effect holds well beyond the elastic limit of nitro-cellulose in tension, and is not a function of the strain. An additional check on the order of accuracy of the measurements upon the steel bar is afforded by comparing the mean stress exerted by the testing machine with the integrated stress area under the principal stress curve p. As the value of q_1 is unknown, its probable value has been calculated from experiments on the nitro-cellulose plate, Table VII, and the ordinates of q_1, Fig. 21, have been subtracted to give the curve of stress intensity. It is then found that the average error is +3·5 per cent., and therefore shows a fair agreement. Additional evidence is afforded by the stress distribution along the sides shown in Table VIII for steel and in Table IX for nitro-cellulose, with equivalent values for steel for comparison. Both sets of readings are plotted in Fig. 21, and the agreement is there seen to be quite close, having regard to the slightly different proportions of the two members. It may be remarked in this connection that the measurements of the steel plate were made at various cross sections when the existence of maximum stresses on each side of the minimum section was unsuspected, and although the evidence was plain, this fact had escaped notice until the optical properties were carefully examined recently.

Taken as a whole, this experimental test of the general theory of stress distribution in elastic materials may probably be considered to be a sufficiently close verification to warrant experiments on optical materials being accepted as applicable

to engineering materials, subject to the limitations expressed and implied by the general theory of elasticity and the laws of photo-elasticity.

The effect of eccentric holes, groups of holes, riveted joints, and the like, affords an ample field for further investigation, and

TABLE IX.

TENSION ALONGSIDE OF XYLONITE TENSION MEMBER 1·00″×·182″ WITH CENTRAL HOLE ⅜″ DIAMETER.							
y (ins.)	·6	·5	·4	·3	·2	·1	0
p	700	780	790	770	700	610	570
STEEL TENSION MEMBER.							
y (ins.)	·8	·66	·53	·4	·27	·133	0
$p_1=\frac{9137}{598}p$ $=15{\cdot}28\,p$	10,700	11,920	12,070	11,770	10,700	9,320	8,710

their great practical importance appears to warrant further photo-elastic investigation, since the simple cases cited here show that the stress distribution in more intricate members must be extremely complex, and that our assumptions in regard to them, although they may bear the test of practical work, are likely to be modified by experimental evidence of the nature and variation of the stress conditions.

In conclusion, the authors desire to express their sincere thanks to the Department of Scientific and Industrial Research for aid in the work, and to Mr. F. H. Withycombe for the construction of the models and experimental apparatus required.

Appendix A.

The expressions in polar co-ordinates for the stresses in a plane are readily shown to be

$$\left.\begin{aligned} \widehat{rr} &= \frac{1}{r}\cdot\frac{\delta\chi}{\delta r}+\frac{1}{r^2}\cdot\frac{\delta^2\chi}{\delta\theta^2} \\ \widehat{\theta\theta} &= \frac{\delta^2\chi}{\delta r^2} \\ \widehat{r\theta} &= -\frac{\delta}{\delta r}\left(\frac{1}{r}\cdot\frac{\delta\chi}{\delta\theta}\right) \end{aligned}\right\} \quad \cdots \quad (1)$$

where χ is a solution of the equation $\underset{r,\theta}{\nabla^4}\cdot\chi=0$. The general solution of this latter equation in polar co-ordinates is

$$\left.\begin{aligned} \chi &= a_0r^2+\beta_0r^2\log r+\gamma_0\log r+\delta_0+A_0r\theta\cdot\sin\theta+B_0r\theta\cdot\cos\theta \\ &\quad +(A_1r^3+B_1r\log r+C_1r+D_1r^{-1})\ (R_1\cos\theta+S_1\sin\theta) \\ &\quad +\sum_{m=2}^{\infty}(A_mr^m+B_mr^{-m}+C_mr^{m+2}+D_mr^{-m+2})\ (R_m\cos m\theta+S_m\sin m\theta) \end{aligned}\right\} \quad (2)$$

from which the following equations for the stresses are derived, viz.,

$$\left.\begin{aligned} \widehat{rr} &= 2a_0+\beta_0(2\log r+1)+\gamma_0r^{-2}+2A_0r^{-1}\cdot\cos\theta-2B_0r^{-1}\cdot\sin\theta \\ &\quad +(2A_1r+B_1r^{-1}-2D_1r^{-3})(R_1\cos\theta+S_1\sin\theta) \\ &\quad +\sum_{m=2}^{\infty}\left[\begin{matrix} m(1-m)A_mr^{m-2}-m(m+1)B_mr^{-m-2} \\ -(m+1)(m-2)C_mr^m-(m-1)(m+2)D_mr^{-m}\end{matrix}\right](R_m\cdot\cos m\theta \\ &\qquad +S_m\cdot\sin m\theta). \\ \widehat{\theta\theta} &= 2a_0+\beta_0(2\log r+3)-\gamma_0r^{-2}+(6A_1r+B_1r^{-1}+2D_1r^{-3})\,(R_1\cos\theta+S_1\sin\theta) \\ &\quad +\sum_{m=2}^{\infty}\left[\begin{matrix} m(m-1)A_mr^{m-2}+m(m+1)B_mr^{-m-2} \\ +(m+1)(m+2)C_mr^m+(m-1)(m-2)D_mr^{-m}\end{matrix}\right](R_m\cdot\cos m\theta \\ &\qquad +S_m\cdot\sin m\theta). \\ \widehat{r\theta} &= (2A_1r+B_1r^{-1}-2D_1r^{-3})\ (R_1\sin\theta-S_1\cos\theta) \\ &\quad +\sum_{m=2}^{\infty}\left[\begin{matrix} m(1-m)A_mr^{m-2}+m(m+1)B_mr^{-m-2} \\ -m(m+1)C_mr^m+m(m-1)D_mr^{-m}\end{matrix}\right](S_m\cdot\cos m\theta \\ &\qquad -R_m\cdot\sin m\theta). \end{aligned}\right\} \quad (3)$$

Now, in the case of a hole in a plate of unlimited width, Fig. 22, subjected to tension, we have when $r = \infty$

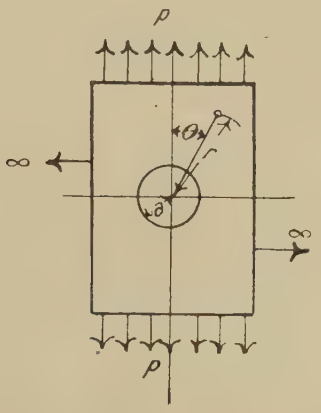


Fig. 22.

$$\left.\begin{aligned} \widehat{rr} &= \frac{p}{2}(1+\cos 2\theta) \\ \widehat{\theta\theta} &= \frac{p}{2}(1-\cos 2\theta) \\ \widehat{r\theta} &= -\frac{p}{2}\sin 2\theta \end{aligned}\right\} \quad - \quad - \quad - \quad (4)$$

and the general expressions must reduce to these forms for infinite values of r. Hence we obtain the following values of the coefficients, viz.,

$$2\alpha_0 = -2A_2\, R_2 = \frac{p}{2} \qquad A_1 = \beta_0 = 0.$$

The coefficients in C vanish for all values of m, and all coefficients in A except A_2. All coefficients in S_1 vanish since the retention of the terms involving S_1 would give unsymmetrical values, while terms in S_2 S_3, etc., are inconsistent with the values of $\widehat{rr}$, $\widehat{\theta\theta}$, and $\widehat{r\theta}$ at infinity. Hence we may write the stresses in the form

$$
\begin{aligned}
\widehat{rr} &= \frac{p}{2} + \gamma_0 r^{-2} + 2A_0 r^{-1} \cdot \cos\theta - 2B_0 r^{-1} \cdot \sin\theta + (B_1 r^{-1} - 2D_1 r^{-3}) R_1 \cos\theta \\
&\quad + \frac{p}{2} \cos 2\theta \\
&\quad + \sum_{m=2}^{\infty} \left[-m(m+1) B_m r^{-m-2} - (m+1)(m+2) D_m r^{-m} \right] R_m \cdot \cos m\theta. \\
\widehat{\theta\theta} &= \frac{p}{2} - \gamma_0 r^{-2} + (B_1 r^{-1} + 2D_1 r^{-3}) R_1 \cos\theta - \frac{p}{2} \cos 2\theta \\
&\quad + \sum_{m=2}^{\infty} \left[m(m+1) B_m r^{-m-2} + (m-1)(m-2) D_m r^{-m} \right] R_m \cdot \cos m\theta. \\
\widehat{r\theta} &= (B_1 r^{-1} - 2D_1 r^{-3}) R_1 \sin\theta - \frac{p}{2} \sin 2\theta \\
&\quad - \sum_{m=2}^{\infty} \left[m(m+1) B_m r^{-m-2} + m(m-1) D_m r^{-m} \right] R_m \cdot \sin m\theta.
\end{aligned}
\qquad (5)
$$

At the periphery of the hole we have for all values of θ $\widehat{rr} = \widehat{r\theta} = 0$ for $r = a$. Hence $A_0 = B_0 = B_1 = D_1 = 0$ and $\gamma_0 = -\frac{p}{2} a^2$.

Also when $m = 2$

$$\frac{p}{2} - 6B_2 R_2 a^{-4} - 4D_2 R_2 a^{-2} = 0,$$

$$\frac{p}{2} + 6B_2 R_2 a^{-4} + 2D_2 R_2 a^{-2} = 0,$$

and for values of m greater than 2

$$
\begin{aligned}
m(m+1) B_m R_m a^{-m-2} - (m^2 + m - 2) D_m R_m a^{-m} &= 0, \\
(m+1) B_m R_m a^{-m-2} + (m-1) D_m R_m a^{-m} &= 0.
\end{aligned}
$$

These equations give

$$B_2 R_2 = -\frac{p}{4} a^4, \quad D_2 R_2 = \frac{p}{2} a^2 \quad B_m R_m = D_m R_m = 0.$$

Hence the function χ is

$$\chi = \frac{p}{4} \left\{ r^2 - 2a^2 \cdot \log r - (r^2 - 2a^2 + a^4 r^{-2}) \cos 2\theta \right\} \qquad (6)$$

and the stresses

$$\left.\begin{aligned}\widehat{rr} &= \frac{p}{2}\left\{\left(1-\frac{a^2}{r^2}\right)+\left(1-4\frac{a^2}{r^2}+3\frac{a^4}{r^4}\right)\cos 2\theta\right\}\\ \widehat{\theta\theta} &= \frac{p}{2}\left\{\left(1+\frac{a^2}{r^2}\right)-\left(1+3\frac{a^4}{r^4}\right)\cos 2\theta\right\}\\ \widehat{r\theta} &= \frac{p}{2}\left\{3\frac{a^4}{r^4}-2\frac{a^2}{r^2}-1\right\}\sin 2\theta.\end{aligned}\right\} \quad (7)$$

The values of these stresses for a series of values of θ and r have been shown in the accompanying Table IX, and their changes are also indicated by diagrams of which Fig. 23 shows the stress variation of $\widehat{\theta\theta}$ along radial lines through the centre of the hole and round its contour.

Fig. 24 shows the variation of cross radial stress, and Fig. 25 the shear stress along a number of radial sections.

Table IX.

Stress Distribution around a Circular Hole in an Infinitely Wide Tension Member.

$$\widehat{\theta\theta} = \tfrac{1}{2}p\left\{1+\frac{a^2}{r^2}-\left(1+3\frac{a^4}{r^4}\right)\cos 2\theta\right\}$$

θ	$r=a$	$r=1\frac{1}{2}a$	$r=2a$	$r=3a$	$r=4a$	$r=\infty$
0°	−1·000	− ·074	·031	·037	·025	0
15°	−0·732	+ ·033	·111	·107	·093	·067
30°	+ 0	+ ·324	·328	·296	·278	·250
45°	+1·000	+ ·722	·625	·556	·531	·500
60°	+2·000	+1·120	·922	·815	·784	·750
75°	+2·732	+1·412	1·139	1·005	·969	·933
90°	+3·000	+1·519	1·219	1·074	1·037	1·000

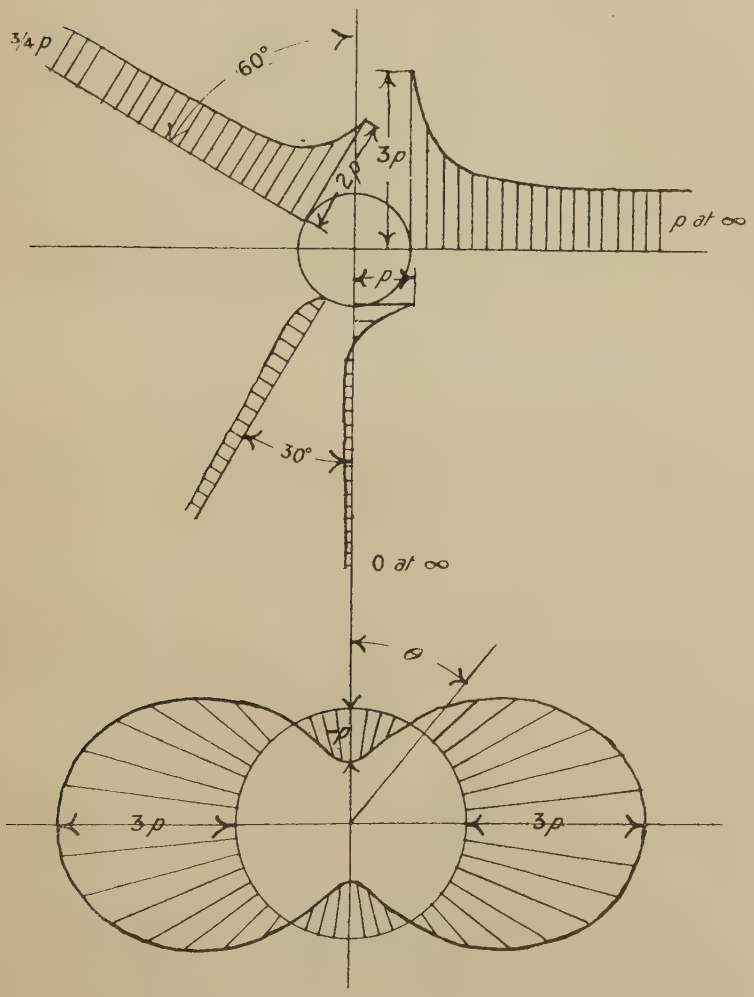
$$\widehat{rr} = \tfrac{1}{2}p\left\{1 - \frac{a^2}{r^2} + \left(1 - 4\frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right)\cos 2\theta\right\}.$$

θ	$r = a$	$r = 1\frac{1}{2}a$	$r = 2a$	$r = 3a$	$r = 4a$	$r = \infty$
0°	0	·185	·469	·741	·850	1·000
15°	0	·198	·456	·701	·799	·933
30°	0	·231	·422	·593	·662	·750
45°	0	·278	·375	·404	·469	·500
60°	0	·314	·328	·296	·276	·250
75°	0	·358	·294	·188	·139	·067
90°	0	·370	·281	·148	·088	0

$$\widehat{r\theta} = \tfrac{1}{2}p\left\{-1 - 2\frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right\}\sin 2\theta$$

θ	$r = a$	$r = 1\frac{1}{2}a$	$r = 2a$	$r = 3a$	$r = 4a$	$r = \infty$
0°	0	0	0	0	0	0
15°	0	—·324	—·328	—·296	—·278	—·250
30°	0	—·561	—·568	—·513	—·482	—·433
45°	0	—·642	—·656	—·593	—·557	—·500
60°	0	—·561	—·568	—·513	—·482	—·433
75°	0	—·324	—·328	—·296	—·278	—·250
90°	0	0	0	0	0	0

$$\widehat{\theta\theta} = \tfrac{1}{2}p \left\{ 1 + \frac{a^2}{r^2} - \left(1 + 3\frac{a^4}{r^4}\right) \cos 2\theta \right.$$



Tangential Stress $\widehat{\theta\theta}$ at Periphery.

Fig. 23.

$$\widehat{rr} = \tfrac{1}{2}p \left\{ 1 - \frac{a^2}{r^2} + \left(1 - 4\frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right) \cos 2\theta \right\}$$

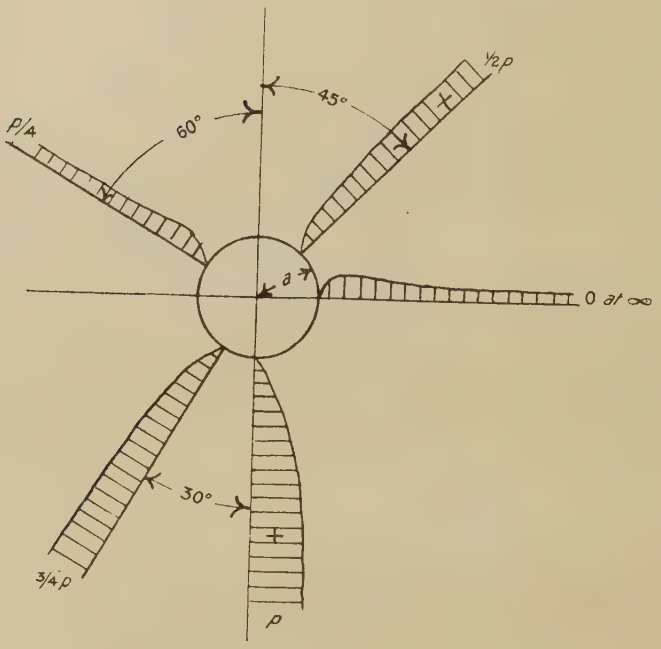


Fig. 24.

$$\widehat{r\theta} = \tfrac{1}{2}p \left\{ -1 - 2\frac{a^2}{r^2} + 3\frac{a^4}{4r} \right\} \sin 2\theta$$

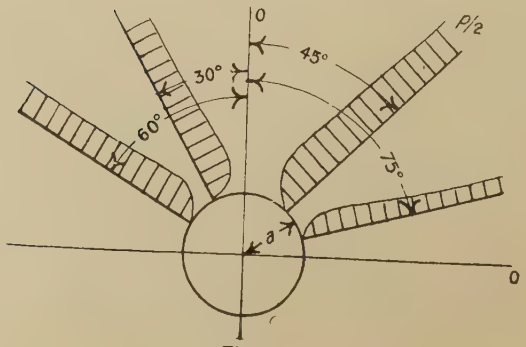


Fig. 25.

Appendix B.

The examples cited in this paper differ from the ideal case in that the uniform stress p corresponding to a plate of infinite width is not ascertainable directly. For comparison purposes its values may be found sufficiently accurate from the assumption that the principal stress variation across the minimum section follows the law given by equation

$$\widehat{\theta\theta} = \frac{\delta^2 \chi}{\delta r^2} \text{ when } \theta = \frac{\pi}{2}$$

$$\widehat{\theta\theta} = \frac{p}{2}\left(2 + \frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right) \quad \text{- - - (8)}$$

If then p_m is the mean average stress across this section, then

$$p_m \cdot a(c-1) = \int_a^{ca} \widehat{\theta\theta} \cdot dr = \frac{p}{2}\int_a^{ca} \left(2 + \frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right) dr$$

where $2ca$ is the width of the members, and therefore

$$p_m = p\left(1 + \frac{1}{c} + \frac{1}{2c^2} + \frac{1}{2c^3}\right) \quad \text{- - - (9)}$$

giving a value of p which may be used for calculation and is so employed here. This expression gives a very fair agreement with the results of experiment for holes of moderate size, and allows of an estimate of the maximum stress p_{max} from the derived equation

$$p_{max} = \frac{6c^3}{2c^3 + 2c^2 + c + 1} p_{mean} \quad \text{- - (10)}$$

If c is large compared with unity the approximate expression

$$p_{max} = \left(\frac{3c}{c+1}\right) p_{mean} \quad \text{- - - (11)}$$

may be employed for stresses within the elastic limit of the material.

Beyond this point equalisation of stress begins to play a part in materials like mild steel, but in very hard materials there is reason to believe that the stress variations measured here persist up to fracture without much change.

Discussion.

Dr. T. Blackwood Murray (President): I am sure you will agree with me that this paper is of great interest to engineers, for tension members with holes in them, the basis of Prof. Coker's investigations, enter very largely into every-day engineering practice. Probably very few could have any idea that the effect of a hole in a tension member was so widespread. We owe a debt of gratitude to Prof. Coker and his assistants for having investigated so fully and in such a scientific manner the distribution of stress in tension members. The results are of immense value, because, from what Prof. Coker says, one can safely allow a factor of safety of three in an average tension member to render it safe from breaking stresses round the hole.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Associate Member): It is really an important matter that the Institution should have among its records some account of the results of the experiments made by Prof. Coker. The subject of the paper is not new, for Prof. Coker brought the matter before the Institution of Naval Architects in 1911, and again in 1913, and, curiously enough, in the same year, 1913, Mr. C. E. Inglis wrote a paper on the mathematics of the subject, corroborating the results which Prof. Coker had already obtained. Concerning these results many points may be raised, but I wish to call attention to a particular point in connection with Fig. 26, which represents the case of a parallel plate having a circular hole in the centre under tension. The curve in the diagram shows the stress across the line of narrowest section through the hole, and, whatever the size of the hole, the curve of stress has always the same general form. It appears to me that the stress at the edge of the hole is always bound to be very much more than the mean stress under any circumstances.

In designing a tension member with a hole in it, it is natural to assume that it is quite satisfactory if a reasonable mean stress is obtained at the narrowest section; but, as a matter of fact, the actual stress close to the hole is from one-and-a-half times to twice the mean stress. To find out the effect of repeated applications of stress to such a tension member might form a subject for research, say, at the Royal Technical College or the University laboratory. I presume the hole would be altered in shape, and especially so if the

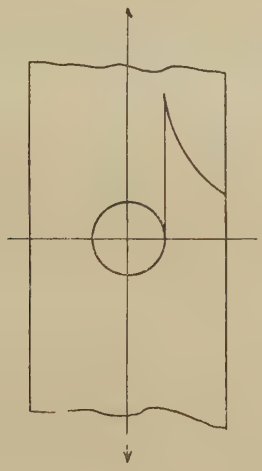


Fig . 26.

mean stress on the section approaches the elastic limit, for, if the mean stress is near the elastic limit, then close to the hole the stress must exceed the elastic limit, and distortion will naturally take place there. The hole must change in shape, and I have been considering if there is not a possible way in which the thickness of the plate may be increased locally to avoid this distortion. Take a tension member four inches by one inch with a two-inch hole in it, then a thick-

Mr. W. H. Riddlesworth, M.Sc., M.Eng.
ness at the narrowest section of two inches is required to bring the mean stress down to that in the unpierced bar, but this still leaves the stress at the edge of the hole very much greater than the mean stress, and, in addition, it would introduce complications of stress distribution where an increase of thickness takes place. Prof. Coker's results lead to the conclusion that in a tension member which is not uniform in section it is impossible to get a uniform distribution of stress.

Perhaps the most surprising result of these experiments and of the investigations they have led to is that, in a very wide tension member with a hole in it of any size, however small, the stress at the edge of the hole is about three times the average stress.

Dr. ANDREW MCCANCE: I was originally drawn to the study of stress distribution through the study of certain steel failures. Steel, no matter how well it is made, always contains small particles of non-metallic matter, and it has been found by experience that when fracture takes place it nearly always follows a path where these non-metallic particles are segregated. Now from the examination of many such cases it seems that certain deductions can be made, but the explanation of the facts presented a certain amount of difficulty until I read Prof. Coker's paper, when possible explanations occurred to me, and I should like to have Prof. Coker's opinion as to whether these are justified or not.

One of the main points about the distribution of stress around holes is that the intensity of stress at the inner edge is independent of the size of the hole, no matter how small the hole is the maximum stress is still three times the average stress, so that even microscopic holes are as important as holes which are much larger. But from Prof. Coker's paper the area surrounding a hole, which is subjected to higher stresses than the average, is shaped something like that in

Fig. 27, and the greatest width at right angles to the direction of stress may be taken as about four times the radius on each side for practical purposes, since at this distance the increase only amounts to four per cent. of the applied average stress. On each side of any hole then, there is an area of disturbance shaped like a two-bladed propeller, and with its greatest width about four times the diameter of the hole. Now I have found that non-metallic particles, so long as they are small and uniformly distributed, do not affect the strength of the steel prejudicially; in fact they have no observable effect on its mechanical properties, but when they are large, or when they occur in clusters or segregates, they are dangerous. Test pieces taken from steel containing them

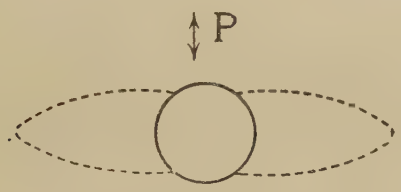


Fig. 27.

under those conditions break with a low contraction and elongation. I think then that the action is this, that if the particles are separated from one another by more than four times their diameter they do not interfere one with the other, and are consequently harmless, but if a particle happens to lie within the area of disturbance of a neighbour, then their stress effects are mutually superimposed, and between them the stress may reach a very high value indeed. And the larger the size of each then the greater chance there is that another particle will be found enclosed within the boundary. I have taken pieces of steel and stressed them above their yield point, and, having examined them microscopically, have found, in fact, that cracks are started in this manner, but

Dr. Andrew McCance.

the explanation never was clear in many cases until this interesting paper put the matter in a new light. Fig. 28 is a reproduction of a photograph of a crack which ran between two small inclusions, and it has puzzled me to understand why a crack should have started between these two when single ones even larger had no cracks in their vicinity although subjected to the same stress. But the explanation given above seems at once reasonable and satisfactory.

Turning to larger holes, if we consider a plate in which holes have been made by punching, the material round the

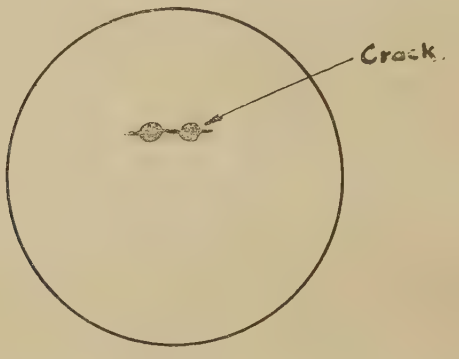


Fig. 28.

periphery of the holes has been strain-hardened by compression, and so the elastic limit in compression will have been raised and the elastic limit in tension correspondingly lowered, while, in addition, it will be more brittle. By brittleness, of a cruiser stern, I present the case of a twin-screw passenger reached fracture may take place with little or no local deformation, and in boiler plates when once a crack has been started it is very difficult indeed to say where it will stop. When such a plate with punched holes is put in tension it is unfortunate that the maximum stresses caused by the hole are located just where, as we have seen above, the material

is least able to stand it, and where the elastic limit in tension is least. The factor of safety may, in fact, be entirely illusory. I have examined plates in which such cracks had been formed, and when they were made visible by etching with strong acid they spoke strikingly of the reality of the stresses with which Prof. Coker's paper dealt so convincingly.

In connection with the general methods of measuring the distribution of stresses in difficult cases, a method which has not been proposed, to my knowledge, may have a field of usefulness open to it under modern conditions. It is known that steel or any other metal under tension stress is cooled when the stress is applied, and the amount of this cooling can be calculated by means of a formula due to Lord Kelvin. Modern pyrometric appliances can measure temperatures accurately within 1,000th of a degree, and it may be possible to determine the distribution of stress by the variations in temperature when the stress is applied. It would have this advantage, that the measurements could be made on the actual steel specimen which would not be destroyed, and they could be confirmed repeatedly if necessary. The expression of Prof. Coker's opinion on the possibility of utilising this property would, however, be very valuable.

Mr. J. L. Adam (Member): After the first feelings of admiration which the work entailed in the preparation of the paper gives rise to, one naturally asks how the information available can be used. Without a careful analysis of the paper it is difficult to see to what extent its results can be applied to such a subject as shipbuilding, but the reader catches glimpses of possibilities which may be reached if Prof. Coker continues the good work, so that shipbuilders and designers of other complicated structures may have a ready means of ascertaining the distribution of the stresses in the completed structure. In the practical theory which enables successful ship structures to be designed

Mr. J. L. Adam.
with reasonable certainty, the basis is largely empirical, and it is not an unheard-of thing for structures to fail which should have been quite successful according to that theory. It is possible that by applying the information which Prof. Coker has gained we may find reasons for these failures, and Prof. Coker would confer a great boon on the shipbuilding world if he could help to solve such problems as the following:—

(a) The distribution of the stresses in a flat expanse formed by strips of steel plating with seams parallel to the line of pull, each strip approximately five feet in breadth, and attached to its neighbour by a line of rivets, and having a round hole, say 24 inches in diameter cut out at the centre of this expanse of plating.

(b) The distribution in this expanse of plating if not absolutely flat, but having, as in the case of deck plating, a slight curvature forming approximately a parabola transversely.

(c) And yet again, in the same expanse of plating, curved as in the second case, but attached in the line of pull to a continuous vertical expanse of plating at the outer edges.

This latter case represents very nearly the conditions arising in the deck of a vessel having a scuttle cut in the centre, or, which is a more useful case to consider, a portion of the deck of a vessel, say that portion between the casings amidships and the vertical plating of the sheerstrake, where of necessity coaling and other openings must be cut. It is frequently necessary to compensate for such openings in the deck plating, and the mean stress is reduced by doubling the plating in way of the hole, or increasing the thickness of that plating abreast of the hole—in each case the increased area giving the same mean stress per unit of material as the unpierced plating. I do not know just how far one can

fairly apply Prof. Coker's formulæ to such cases, but it would appear on the surface that the place to apply the compensation economically is around the opening, and to a limited extent this is borne out by practice. Square and rectangular openings come under a different category, but it seems reasonable to suppose that, if the investigations were pushed a little further, some more light would be thrown on the case of rectangular openings with rounded corners.

Frequently there is met the case of a round hole cut in plates or expanses of plating in which the pull is greater at one edge than at the other, and it is reasonable to expect that this condition might be resolved by evolution along the lines suggested by Prof. Coker; and if this condition, why not that of a rectangular hole with round corners under the same conditions? I crave Prof. Coker's indulgence, but it is certain that shipbuilders of the future will no more tolerate such waste of material as may take place to-day, than the shipbuilder of to-day would tolerate the useless and uneconomical distribution of material put into ships in the early days of steel shipbuilding.

If I may be permitted to say so, I think that, great as is the intrinsic value of the paper, it is of even greater value in the promise it gives of a useful field of investigation towards a solution of everyday problems such as have been mentioned.

Mr. James Richardson, B.Sc. (Member):—Prof. Coker's paper evokes the highest praise for the beautiful manner in which the results of this individual research on the subject of strain measurements have been presented, as well as for the ample manner in which proofs have been given of all the deductions made. It is, furthermore, most interesting to learn that the results of the experiments with nitro-cellulose specimens have been proved to hold equally well for other materials with which the engineer is concerned, such as steel.

Mr. James Richardson, B.Sc.

The work of Dr. McCance, as given last session before this Institution, further confirms that the behaviour under stress of these two vastly different materials, nitro-cellulose and steel, is similar. It is to be observed that Dr. McCance's method of measuring the hardness of a piece of material strained beyond the elastic limits only serves to locate and to assess the maximum stresses, and not to resolve these stresses into their components. This method as a means of determining the cause of failure is immensely practical, and lends itself to workshop application, all that is required being a Brinell meter, and there are to be obtained at the present time some very handy forms of this machine. Prof. Coker's solution, on the other hand, will aid the designer of members of a new mechanism without actual trial and experiment entailing stressing beyond the elastic limit, and as such, must when appreciated, be of great service in practice.

The particular example so thoroughly treated in this paper, that of a hole in a plate, naturally brings to mind the subject of riveted joints. There can be little doubt that Prof. Coker's work clearly shows the rules and formulæ at present applied to the design of such an important item of engineering work to be little more than merely a handy means of ensuring that successful past experience is followed, and that the factor of safety is sufficiently large to bridge any want of definite knowledge. In the light of the paper we have been privileged to hear, it can confidently be hoped that a more sure basis on which to work in the future is not remote. In certain essentials Prof. Coker's experimental work to date cannot be applied to riveted structures. The closing of the rivet imposes a most important tensile stress on the material in the vicinity of the hole which must be added to the tension or other stresses already considered. Whether the hole be punched or drilled further affects the material in way of the hole. As regards drilling, it has been shown that the material is only affected to

a depth of some ·005 to ·0075 of an inch, depending in measure upon the sharpness of the drill, whereas with a punched hole the material around the hole is stressed by punching to a depth of approximately half the diameter of the hole. With Prof. Coker's specimens, I believe that after the hole had been machined the stressed layer was carefully scraped off the inside of the hole, so removing this stress from the scope of the investigation. Apart, however, from riveted structures, which present rather a difficult subject, the practice with modern engineering to work for high speeds often imposes restrictions on the weight of moving parts to meet which lightening holes are drilled, and such members of a mechanism form an excellent subject for investigation, according to Prof. Coker's photo-elastic methods.

Prof. E. G. Coker, M.A., D.Sc., F.R.S.: We desire to express our cordial thanks for the appreciative interest shown in the paper by the President and Members, and also for the helpful suggestions and criticisms which have been contributed by various speakers. It is hoped that, although the cases selected for experiment are simple compared with those usually met with in practice, they will be helpful to engineers in forming an estimate of stress distribution, as the President kindly suggests.

Mr. Riddlesworth, in referring to some earlier work of Prof. Inglis which confirms experimental results made some years ago, draws attention to a characteristic feature of the stress distribution across the narrowest section through the hole, in that the variation of stress always has the same general form and the stress at the edge of the hole is always much greater than the mean average stress. As he points out, this is of importance, as designs based on average stress are misleading and may be dangerously weak. It seems probable that a tension member pierced by a central hole would soon fail if loaded by repeated application of stress, having a mean average value near the elastic limit, and especially so with hard and brittle

material in which there is not much change in the general character of the stress distribution under any load. Although the experiments show such great stress variations, it does not seem to be an impossible task to devise members having holes and notches in them, so that the stress is made fairly uniform by altering the thickness. An attempt to show the possibility of this is made in an earlier paper, read before the Institution of Automobile Engineers in 1917, by thickening the material around the hole in order to reduce the intensity of stress at the place of danger. It is probable that a fairly uniform stress condition can be reached by such means, and that a variety of such cases of practical importance can be dealt with in a simple manner. Some of these are described in outline in the paper referred to.

The effect of the presence of small particles of non-metallic matter in steel raises some questions of primary importance, which Dr. McCance discusses at some length; we agree with his general conclusions. The effect of a small cylindrical hole bored through a plate increases the intensity of stress three times along two generating lines, but in general it would probably be more accurate to consider such small inclusions of foreign matter as approximately spherical cavities, for which the analysis of Prof. Love* shows that the great stress intensity is nearly twice the average along the great circle perpendicular to the direction of stress. In any case the cavities, whether of cylindrical or spherical form, raise the maximum stress intensity very considerably, and it is interesting to watch the effect of the grouping of such holes in a tension member made of transparent material. If cylindrical holes are employed in a line parallel to the axis, they appear when not too close to produce effects which do not interfere with one another, nor give a cumulative effect, while the region between the holes is

* "The Influence of Flaws and Air Cavities on the Strength of Materials," by J. Larmor. "Philosophical Magazine," 5th Series, Vol. xxxiii, 1892.

apparently hardly stressed at all; but if the holes are across the section the regions of most intense stress are now between the holes, and the danger of a crack commencing is much increased, as Dr. McCance points out. The effect of a line of holes across the member has been measured, and the results are given in an earlier paper. The effects of groups of holes have, however, only been examined in a fragmentary way.

The thermal phenomena accompanying stress discovered by Lord Kelvin from theoretical considerations, and subsequently confirmed by Joule's experiments, have been occasionally used by experimental investigators, notably by Turner,* although his conclusions as to the existence of low elastic limits in engineering materials is clearly an error, due to neglect of experimental conditions.

As an expression of opinion on the possibility of utilising this property is invited, it may not be out of place to briefly describe its possibilities, and also the special difficulties of experimental investigation of stress distribution encountered by one of us when using this property of materials for research purposes some 15 years ago.

A simple calculation based on the thermo-elastic equations shows that the change of temperature in steel is approximately one-tenth of a degree C. for a tension or compression stress of 8,000 pounds per square inch, and that the effect for compound stress is additive or of the same type as the lateral measurements used in this paper. The smallness of the temperature change is no bar to its use for stress purposes, as with a properly constructed thermo-pile and low resistance galvanometer a change of one-millionth of a degree can be made perceptible. The most difficult matter is to prevent the small change of temperature encountered being altogether swamped by radiation and convection to the surrounding atmosphere, and to a

* "Thermo-Electric Measurements of Stress." Trans. American Society of Civil Engineers, 1902.

smaller extent by conduction to the testing machine. It is to be noted that the thermal effect is a transient one, and in practice load must be applied at such a rate that the lag effect of the thermo-pile and galvanometer has no effect on the measurements. The simplest method of overcoming this latter difficulty was found to so proportion the rate of loading that for any load the deflection of the galvanometer is a maximum for the load reached.

This method of procedure, however, gives a maximum value

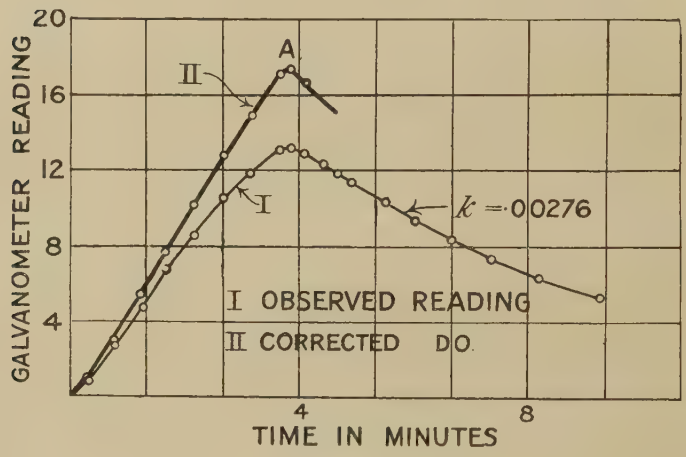


Fig. 29.

which is considerably less than the real value of the Kelvin thermal effect, owing to the combined effect of radiation, convection, and conduction. It is found that the combination of these produces a diminution proportional to the change of temperature. A correction is therefore necessary. To take a concrete example, the curve I, Fig. 29, shows the observed readings of the galvanometer connected to a thermo-pile applied to the face of a steel tension specimen 2 inches by 0·375 inch in cross-section when the load was increased uniformly from 500 lbs. to 16,000 lbs. in 220 seconds, and then held steadily at this

latter value. The curve shows no linear relation for the reasons stated above, and it is easily shown that if θ be the total actual change of temperature instead of θ_0 per unit of time, the relation between them is

$$\frac{d\theta}{dt} + k\theta = \theta_0$$

where the term $k\theta$ represents the effect of the disturbing factors already described, and t is the time.

Eliminating these latter, the change of temperature T can be expressed in the form

$$\theta_0 \ t = \mathrm{T} = \theta(1 + \tfrac{1}{2}kt)$$

to a considerable degree of approximation while the value of k is found, as may be readily shown, from the tail of the observation curve by the expression

$$k = \log_\epsilon \cdot \frac{\mathrm{D}_1}{\mathrm{D}_2} (t_2 - t_1)$$

where the deflections D_1 and D_2 correspond to the times t_1 and t_2. Applying the correction to curve I, we obtain a new curve II, in which the relation of load to change of temperature is linear, and the reading at the peak A measures the true effect of the load. Proceeding in this way it is possible to study the stress at a point in a body under load, and a variety of experimental determinations have been described in various papers* to show the scope of the method.

As is apparent from the single experiment quoted, work of this kind is very laborious and somewhat difficult. It usually requires the co-operation of two or three skilled observers. The phenomena observed are transient and liable to considerable interference from draughts, currents of air, and slow changes of temperature. They can, however, be applied to metals

* "The Relation of Thermal Change to Tension and Compression Stress," by Prof. E. G. Coker and C. M. McKergow. Trans. Royal Society, Canada, 1904. "On the Measurement of Stress by Thermal Methods," by E. G. Coker. Trans. Royal Society, Edinburgh, 1904. "The Measurement of Stresses in Materials and Structures," by E. G. Coker. Cantor Lectures, Royal Society of Arts, 1914.

directly, an advantage, however, which is usually overestimated. The observations must usually be confined to the surface, as any hole made to accommodate a thermo-couple in the interior entirely upsets the distribution of stress in its neighbourhood. The results are therefore taken at the surface, while measurements obtained photo-elastically are an average throughout the thickness. Beyond the limit of perfect elasticity internal friction causes a rise of temperature of relatively large amount, and this change has been successfully utilised by Mr. Stromeyer* to show when fatigue begins in alternating stress. It may also be noted that pure shear has no thermal effect, since this type of stress may be resolved into two equal simple stresses of opposite signs acting at a point. For some types of problems, therefore, it may be said that thermal measurements possess superior advantages, but as a general method of attack photo-elastic determinations are superior as regards accuracy and ease of measurement of stress distribution.

The application of measurements of stress distribution to ships' hulls and other complicated structures, in which riveted joints are of the first importance, is a particularly intricate field of research of special interest to naval architects. Some attention has already been given to the possibilities of photo-elasticity in this field, and sufficient work has been carried out to demonstrate its possibilities.

The stress in a ship's deck offers a good example, and has been examined for the case of the deck of a torpedo-boat destroyer built by Messrs. Yarrow about 10 years ago. In this case a model was constructed from drawings kindly supplied by this firm, and the stress distribution was examined across sections through a funnel opening and also the main engine hatchway, for a simple type of loading such as may be imagined to occur in a vessel meeting long waves head on and with one

* The Manchester Steam Users' Association. Memorandum by Chief Engineer for the year 1913.

crest at about the central section and the bow and stern in the troughs of the wave.

The measurements were described in the Transactions of the Institution of Naval Architects, 1911. In the interval more experience and knowledge has accumulated, and it is possible to make a fairly definite reply to the questions asked by Mr. J. L. Adam. There would probably be no great difficulty in determining the stress distribution in a wide expanse of steel plating with seams parallel to the line of pull and of the dimensions and form stated. The riveted joints are probably the only serious difficulties, but as these are all of a simple type, with only one or two lines of rivets, the measurement of the distribution appears to be feasible. The distribution in deck plates of slight curvature (b) free at the sides or (c) rigidly attached to the hull might give some trouble, especially in the latter case, if the applied loads caused a further transverse bending of the expanse of plating, and thereby causing varying stress throughout the thickness. This stress distribution could, however, be measured if the loading contemplated allowed a thin transverse section to be examined.

The effect of rectangular openings and other discontinuities in which the pull is variable over the cross-section is now engaging the attention of one of my research students, Mr. M. S. Ahmed, and so far as these experiments have progressed they appear to justify the belief that in such cases the stress distribution can be measured with fair accuracy.

The stress in the complex riveted joints, which engineering practice requires, affords the most difficult cases which can occur, whether considered as mathematical or experimental problems, and the simple rules which have been evolved to deal with various cases, although perfectly justifiable in our present state of knowledge, tend to obscure the essential complexities which occur. Mr. Richardson's view that such rules and formulæ are " little more than merely a handy means of

Prof. E. G. Coker, M.A., D.Sc., F.R.S.

ensuring that successful past experience is followed, and that the factor of safety is sufficiently large to bridge any want of definite knowledge," does not seem to be an overstatement, but a remedy is difficult to find, and if it is found it will probably come, not from experiments on complicated joints, but rather from an analysis of all the different elements of the problem taken separately. To that end some attempt is now being made in the laboratory at the University College to solve each bit of the problem apart from the others, with the eventual hope of a more rigorous scrutiny later on of the problem as a whole. It is of interest to mention in this connection that one of my research students, Prof. Fukuda, of the Tokio Technical College, has recently completed an experimental analysis of the stress produced by a pin pressed against a hole in a very wide plate, and that the effects of the proximity of various forms of contour with respect to the pin have been examined by Messrs. K. C. Chakko and M. S. Ahmed. Some minor details still require consideration before publication is possible, especially as the essential features, although in general agreement, are somewhat different from those expected.

The closing of the rivet is an element mentioned by Mr. Richardson as imposing an important distribution of stress in the neighbourhood of the hole, and it may be added that this introduces a factor which is highly variable from rivet to rivet, and it is easy to show optically that the position of the hole with respect to the contour of a plate or other rolled section exerts a very great effect. The different effects of drilling and punching are also to be considered. Incidentally it may be remarked that nitro-cellulose, like steel, after drilling in the ordinary way, shows a thin layer of over-stressed material at the boundary, which can be removed by a fine file, as Mr. Richardson points out, but in more recent work it has been found practicable and more convenient to remove this final layer by a revolving cutter shaped to a razor edge, thereby affording a more accurate contour.

THE CRUISER STERN.

By P. A. Hillhouse, B.Sc.

25th November, 1919

As the application of the cruiser stern to mercantile vessels has apparently "come to stay," I trust that a short discussion of its history, features, and merits or demerits may be of interest to our shipbuilding and shipowning members.

The first large liners to have the cruiser stern were the "Empress of Russia" and the "Empress of Asia," built in 1913, although the coasting steamers "Prince Rupert" and "Prince George" had been so constructed in 1910, and the Wilson Liner "Borodino" in 1911. The Empresses were followed by the Allan Liners "Calgarian" and "Alsatian," and the fashion spread so rapidly that Lloyd's Register now contains the names of over 150 vessels followed by the caption "Cruiser Stern."

The early merchant vessels had but a small extension of the deck beyond the sternpost, designed probably with the object of housing the rudder stock, and affording space and protection for the tiller and steersman. This projection being found both convenient and sightly, gradually increased in extent until the ordinary "overhanging counter," "elliptical," or "armchair" stern became, and remained for many years, the standard practice in mercantile design. The taffrail of the "Britannia," the first Cunarder, overhung the sternpost by about eight feet; the "Britannic" had a projection of 32 feet.

Naval vessels developed in quite a different fashion. In

order to reduce weight and target as much as possible, war vessels had usually much less freeboard than their mercantile contemporaries; their decks aft were much nearer to the water-line, and as it was known that length of water-line was favourable to speed, the underwater body was extended as far as possible aft of the sternpost, forming an immersed counter or cruiser stern. This immersion of the counter which really gave to the designer a working length considerably in excess of the nominal length—was, in fact, a kind of innocent deception which deceived nobody. There was no valid reason beyond custom, sentiment, and inertia to prevent the same principle being applied to merchant vessels, and as soon as the "elliptical stern" tradition had been boldly broken, and the advantages of immersing the counter fully realised, the new stern made rapid progress, and is now in a fair way to become universal. The projection was there, 20 or 30 feet of it, and the vessel was occupying just so much more quay and canting space than her nominal length. The cruiser stern merely makes water-line length equal to over-all length, and utilises the whole length of the vessel for displacement and propulsive purposes. The change from overhung to immersed counter may be regarded either as cutting off an unnecessary excrescence, and bringing the rudder further forward, Fig. 1a, or as an extension of the ordinary overhang downwards to and below the water-line, Fig. 1b.

As an example of the advantage obtained by the adoption of a cruiser stern, I present the case of a twin-screw passenger and cargo vessel, 550 feet in length, in which it is desired to carry 2,800 tons of cargo in addition to passengers, stores, and water, and fuel for a voyage of 3,000 miles, at a mean speed of 18 knots.

The particulars of such a vessel, if constructed with the ordinary overhung counter, would be approximately as follows:—

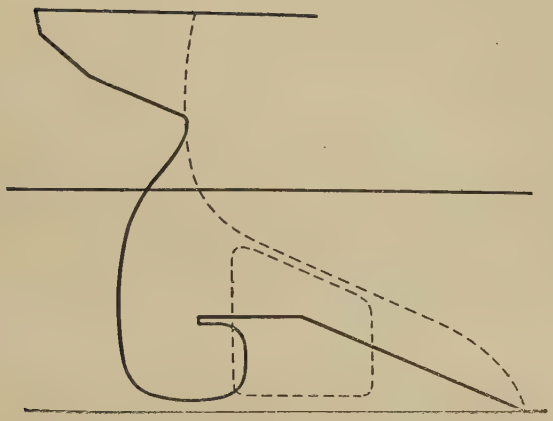


Fig. 1a.

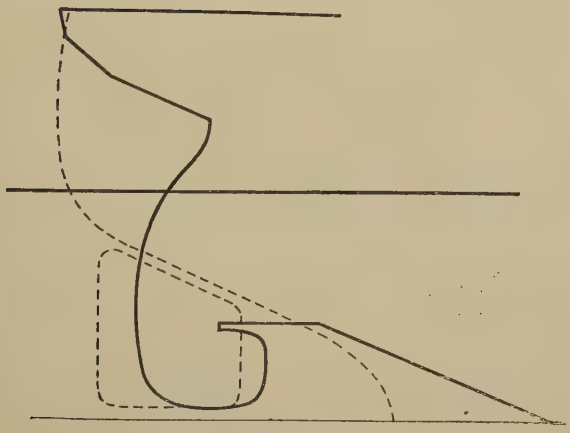


Fig. 1b.

Length between perpendiculars			550 feet.
,, over all			570 ,,
,, on water-line			550 ,,
Breadth moulded			70 ,,
Depth to bridge deck			54 ,,
	Tons.		
Weight of hull	11,200		
,, ,, machinery	2,800		
		Tons.	
Light weight			14,000
	Tons.		
Fuel for 3,000 miles	1,970		
,, 2 days spare	570		
,, use in port	160		
Total fuel		2,700	
Passengers, stores, and water		1,500	
Cargo		2,800	
Total deadweight			7,000
Load displacement			21,000
,, draught (moulded)		28 feet.	
,, block coefficient		·682	
Deduct half fuel consumption			985
Displacement half-way			20,015
Draught moulded half-way		26 feet 10½ inches.	
Block coefficient half-way		·677	
Mean speed		18 knots.	
Speed-length ratio, $V \div \sqrt{L}$		·768	
Horse-power		17,650	
Admiralty coefficient		245	

If now the ordinary overhung counter be replaced by a cruiser stern, the counter being well immersed so that both the water-line and the curve of cross-sectional areas can be carried out fairly to the end of the stern, it will be possible

to add about 20 feet to the effective length of the ship. The speed-length ratio and the block coefficient can both be correspondingly reduced, with a consequent decrease in horse-power. This saving in power enables one in turn to cut down the weights of machinery and fuel, and so to fine the form still further and save more power. This process can be repeated until at last a balance is reached at the point where the displacement necessary to carry all the required weights is just the displacement which can be driven at 18 knots by the power installed. We then have:—

Nominal length		550 feet.
Length over all		570 ,,
,, on water-line		570 ,,
Breadth moulded		70 ,,
Depth to bridge deck		54 ,,
	Tons.	
Weight of hull	11,200	
,, ,, machinery	2,575	
		Tons.
Light weight		13,775
	Tons.	
Fuel for 3,000 miles	1,750	
,, 2 days spare	505	
,, use in port	160	
Total fuel	2,415	
Passengers, stores, and water	1,500	
Cargo	2,800	
Total deadweight		6,715
Load displacement		20,490
,, draught (moulded)	28 feet.	
,, block coefficient	·642	
Deduct half fuel consumption		875
Displacement half-way		19,615

Draught moulded half-way	27 feet.
Block coefficient	·637
Mean speed	18 knots.
Speed-length ratio, $V \div \sqrt{L}$	·755
Horse-power	15,675
Admiralty coefficient	272

In the above it is assumed that any consumption of stores, domestic water and reserve feed-water is compensated for by the addition of salt water ballast for the maintenance of stability and trim, so that the only reduction of displacement that can be taken advantage of is that due to consumption of fuel.

It will be seen that the adoption of the cruiser stern has resulted in a saving of nearly 2,000 horse-power and of 220 tons of fuel per trip, or about 11 per cent.

The area of the upper deck will be increased in proportion to its extra length, as the effect of the lesser block coefficient will hardly be felt in the upper works; the water-line area will be the same in either ship, while the space available for the stowage of cargo will be practically identical in the two vessels, since the capacity lost on account of the fining of the extremities of the cruiser-stern vessel will be compensated for by the lesser volume occupied by machinery and fuel.

On a shorter trip, from port to port, the economies would not be so great, since the saving in weight of fuel would be less; on a longer voyage still more favourable results could be realised.

The swift cross-channel steamer presents a somewhat different problem, as in this case the total fuel consumption is small, and the block coefficient is probably already at its optimum value. In such vessels, however, the "M" value or ratio of length to cube root of displacement is of great importance, and the increase in this factor obtainable by the addition of even a few feet to the water-line length will, in

combination with the reduction in speed-length ratio, have a favourable effect upon propulsion.

Although the immersed counter form applied to merchant steamers is conveniently referred to as a cruiser stern, yet in reality the merchant cruiser stern and the naval cruiser stern are very dissimilar in appearance. The single common factor is that of the immersion of the counter, and this is, of course, the *raison d'être* of this type of ending. In the warship, however, the deck at which the top of the stern profile ends is much nearer to the water-line, and of very much finer form than in the case of the merchant vessel. The mercantile owner

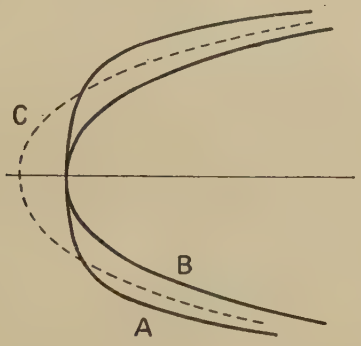


Fig. 2.

is accustomed to a deck ending in a very full so-called "elliptical" curve, as shown by the line A in Fig. 2, and if offered a smaller area in the form of line B, he is apt to feel that he is being defrauded, and to ask why the builder proposes to cut away so much of his deck area aft. The ship is probably built to the fuller deck line, and it thus becomes difficult to make the merchant cruiser stern a thing of beauty, as the bulging deck plan does not harmonise well with the necessarily fine ending to the water-line. This want of harmony becomes accentuated if the profile of the stern "tumbles" forward, as in Fig. 3, and such a contour, if associated with a full

deck line, is apt to produce a stern giving the impression that it had been forcibly bumped forward at the top, and that the

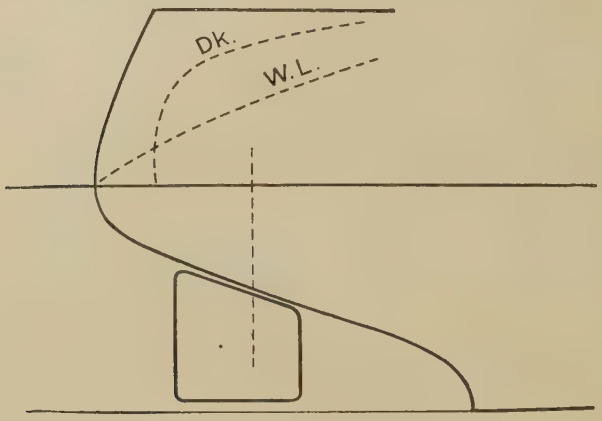


Fig. 3.

sides had bulged outwards in consequence of the blow. A more harmonious appearance can be obtained by tumbling

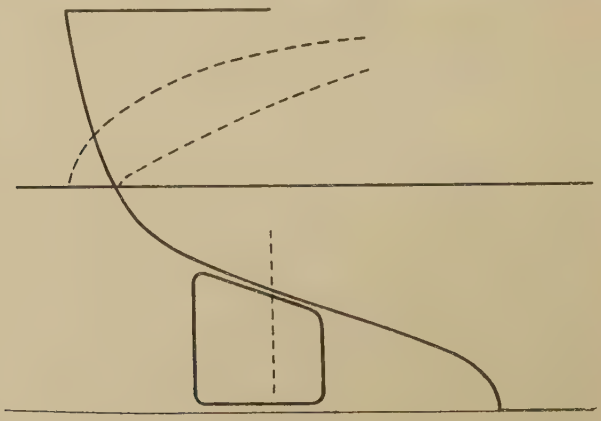


Fig. 4.

the contour aft, as in Fig. 4, and line C, in Fig. 2, and fining the deck line, although in this case some of the over-all length

is again devoted to appearance and not to useful immersion, and the owner will probably still be averse to the fine deck end.

The earlier merchant cruiser sterns were associated with the small propellers of direct turbine drives, and no trouble was experienced in satisfactorily housing the propellers within the half-breadth of the ship.

Fig. 5 compares the cross sections in way of the propellers for a vessel with ordinary stern and reciprocating engines, and for a vessel with cruiser stern and direct turbines. In both

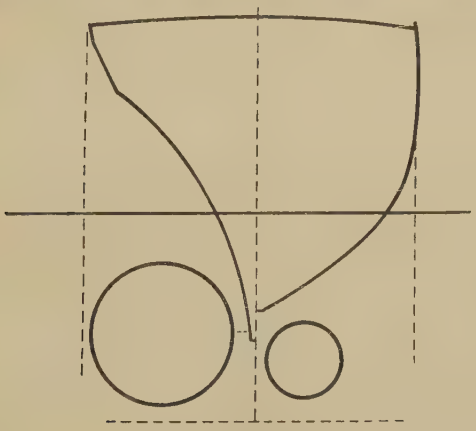


Fig. 5.

cases the deck projects beyond the propellers, although in the case of the ordinary stern the protection obtained is more imaginary than real, since the deck edge is so high up that quay-walls or barges may easily come into contact with the propeller without touching the deck.

But the progress of marine engineering has rendered the direct drive almost obsolete for merchant work, and standard practice is now to fit either single-reduction or double-reduction geared turbines. The larger propellers so obtained are much more efficient, but it is much more difficult to place them satisfactorily abreast of the cross sections of the cruiser form

of stern, and it appears probable that the cruiser stern might never have been adopted for merchant work had its introduction not been facilitated by the small size of the propellers prevalent at the time.

To obtain full advantage of the immersion of the counter it is desirable that both the water-line and the curve of cross-sectional areas should be carried without hollow or " tail " right out to the end of the stern profile. With the ordinary stern the propellers were usually placed a few feet forward

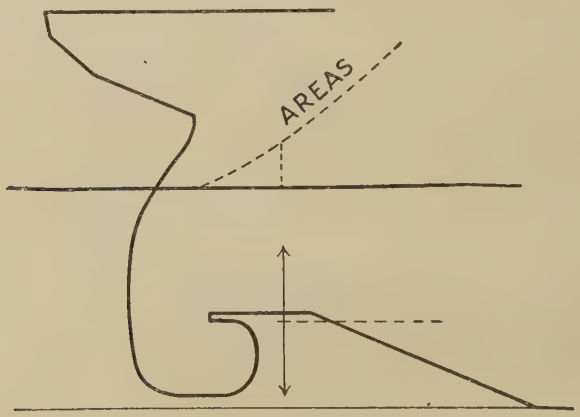


Fig. 6.

of the sternpost from which the water-line and area curve begin, Fig. 6, and were thus associated with very small transverse ship dimensions.

In the case of the cruiser stern, however, the propeller is further forward in relation to the beginning of the area curve, Fig. 7, and so comes abreast of a much larger cross-section, and it is consequently more difficult to house it satisfactorily. Baker, in the excellent paper he read before this Institution last February, pointed out that it is desirable to keep the final angle of run of the water-line to about 20 degrees, and in any case to not more than 25 degrees, from the middle line. We are thus faced with the difficulty of obtaining in

way of the propellers a cross section having a narrow water-line (to work in the 20 degrees angle), a large area (to avoid hollow in the curve of areas), and a wide deck (to please the owner and to protect the propeller). A full rounded section, Fig. 8, will give deck breadth and area, but not the 20

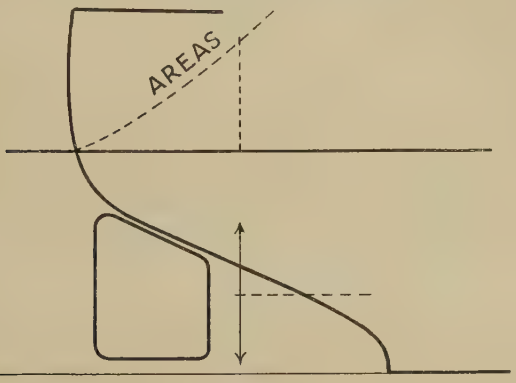
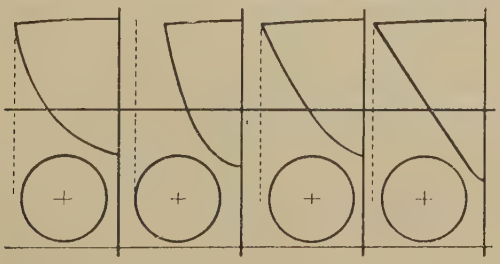


Fig. 7.

degrees water-line. A more vertical section, Fig. 9, will give the desired water-line and curve of areas, but not the deck breadth. In this case the profile would probably



Figs. 8, 9, 10, 11.

have to be tumbled forward and the deck line made very fine. Fig. 10 gives the broad deck and fine water-line, but necessitates a hollow in the curve of areas. To obtain all three desiderata we are apparently forced to make the cross-section abreast of the propeller practically straight, as in Fig.

11, at the same time placing propeller and rudder as far aft as possible, and so obtaining the profile shown by Fig. 12.

Many advantages have been claimed for the cruiser stern in addition to its beneficial effect upon propulsion, and without

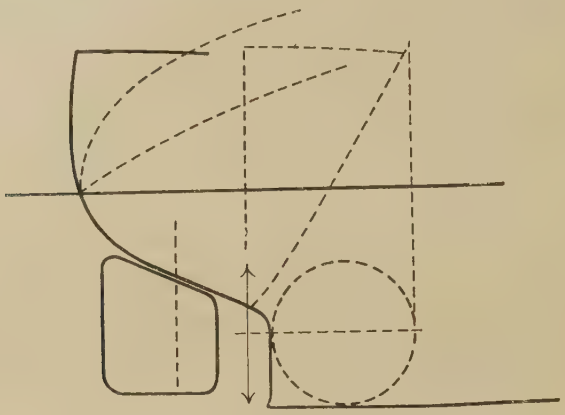


Fig. 12.

pressing any of such claims too far, I think it can fairly be stated that, as regards cost, strength, stability, seaworthiness, and absence of vibration, the new form is at least as good as its predecessor.

Discussion.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Associate Member): The subject of this paper is one in which I have taken a considerable amount of interest for many years. Referring to the historical review in the second paragraph of the paper and Mr. Hillhouse's remarks "That the cruiser stern might never have been adopted for merchant ships had its introduction not been facilitated by the small size of the propeller prevalent at the time," I may add that about 20 years ago an attempt was made to design a cruiser stern for a merchant ship with the then existing type of propeller. A considerable amount of time was spent over the matter, and a great deal of thought given to it, but eventually it

Mr. W. H. Riddlesworth, M.Sc., M.Eng.

had to be abandoned. It was found impossible to work in anything like the existing deck area or anything like the existing propellers, and to extend the under water body of the ship as far as was required.

I should be glad if Mr. Hillhouse would add a little information to the third paragraph of his paper regarding the comparison of the length of the counter. As it stands, it looks as if one vessel had four times as much counter as the other. It would be an advantage to state the percentage of length in each case. If the counter outline of the one ship were superimposed on that of the other, it might be found that the difference was not very great. I am not in accordance with Mr. Hillhouse when he says "This immersion of the counter which really gave to the designer a working length considerably in excess of the nominal length—was, in fact, a kind of innocent deception which deceived nobody." I think in a way it deceived everybody. To take one point only, upon which a great many other things hang, the question of the strength of the vessel—it will be admitted that the principal stress to which the structure of the ship is subjected is due to the support given to the weight of the ship by the water, and of the features of that support the most important, as regards bending-moment, is the length. Referring to the example in the body of the paper, in the one case the weight is supported by the pressure of water spread over 550 feet, and in the other over 570 feet; this must necessarily give different values to the bending-moment, and it is my opinion that almost all stress investigations that have been made on ships with cruiser sterns have been subject to this confusion, and that persons have been deceived because the nominal length only was used. In that way I think the deception was not innocent, and, more than that, the Registration Societies which regulate scantlings of merchant ships were deceived for some time. The scantlings of a ship which

Mr. W. H. Riddlesworth, M.Sc., M.Eng.

depend upon the length where regulated by the distance from the fore side of the stem to the centre of the rudder stock, and the position of the centre of the rudder stock, bore no definite relation to the length over which the supporting forces were applied to the ship. It dawned upon them later that they were being deceived, and they made a rule that the length to be taken for regulating scantlings was not to be less than 96 per cent. of the actual immersed length, or the overall length, as the case might be. That raises the question of what is the proper allowance of weight for two ships which have the same overall length, one with a cruiser stern and the other of ordinary form—a very important and complicated matter with which I do not propose to deal, rather leaving it for some other member to consider.

Mr. Andrew Hamilton (Member): Having had to do with a good many cruiser-sterned cargo steamers, I consider the cruiser stern an advantage. One may have a belief in a thing, but at times it is impossible to confirm that belief on account of the difficulty of acquiring exact data. In Fig. 13 the full line shows a cruiser stern, whilst the broken line represents the ordinary stern, both in elevation and plan of load water-line. A B indicates the position of the rudder post where the ordinary water-line finishes, as shown by the broken line. The full line of the cruiser stern gives a better water-line, and in a 470-foot vessel something like from 24 to 28 feet width will be obtained at the position A B, instead of the water-lines ending there. I refer to vessels having a single propeller of about 18 feet diameter, where the fuller water-line does not obtain until a draught of over 20 feet is reached, the draught increasing up to, say, 27 feet, giving 7 feet of cruiser stern immersed at the load condition. In a 470-foot single-screw ship, the cruiser stern gives about 4,000 cubic feet more space than the ordinary stern in a vessel of the same overall length.

Mr. Andrew Hamilton.

Tank model experiments were made on models of these types, with ordinary and cruiser sterns respectively, and it was found that the full-lined form took about 2½ per cent. less horse-power to drive it at a speed corresponding to 12

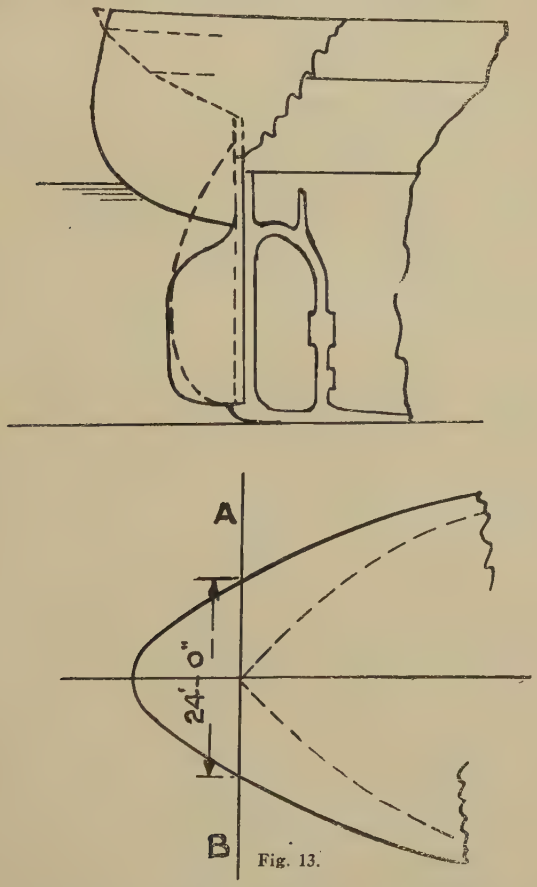


Fig. 13.

knots for the ship. The ships were each 470 feet long, both having turbine machinery, and, taking the results of working during two years, the ship with the cruiser stern appeared to be about 2¼ per cent. better than the other. It is very

Mr. Andrew Hamilton.

difficult to say in actual practice that one is getting a great improvement, but the cruiser stern gives extra space with no extra power, and when the ship is loaded a considerable part of the weight of stern is water-borne, giving equally as seaworthy a boat, and, in my opinion, it is worth the extra cost of fitting. I quite agree that with the cruiser stern, twin screws should give better results than a single propeller. The cruiser stern has come to stay because of its definite advantages, and time only is required to overcome prejudice to change.

Mr. G. S. Baker, O.B.E.: Mr. Hillhouse's paper is really confined to the consideration of the propulsive effect of a cruiser stern on vessels of one type doing about 18 knots on 550 feet length. Generally speaking for this class of vessel, there is little doubt that the cruiser stern can be made of considerable advantage in reducing resistance, and therefore coal consumption. Towards the end of the paper Mr. Hillhouse points out the difficulty of lining out these sterns without filling out the water-line beyond the 25 degrees mentioned in the paper by Mr. Kent and myself, read before the Institution last February. This angle was fixed by us for cargo-boat forms with the ordinary raised counter, and, although we have no concise data to go on, my opinion is that it could be increased with advantage for cruiser sterns, if the vessel is really hard up for length as regards wave-making. It has to be remembered that a *very* full load water-line aft may tend to give transverse sections with a lot of hollow in them just about, or a little forward of the propeller, and greater clearance between propeller tip and hull would then be necessary to get the best result with the propeller, as this is not likely to improve in efficiency if the flow to it is restricted by the form of ship.

Cruiser sterns have been adopted in a number of relatively slower vessels than those considered in the paper, but for such vessels their effect on propulsive efficiency is rather

different. In such vessels the object is to eliminate eddy-making on the upper levels, and although improvement in wave-making may also result, the former is the chief thing considered. In these boats the propulsive advantage of a cruiser stern is never very great—not nearly so much as that for the faster vessel dealt with in the paper—and its adoption has been largely due to considerations apart from simple propulsion. It may be of interest to record that the first vessel of this type with a cruiser stern was tested in the Froude Tank in July, 1913.

Mr. John Anderson: I think we all know that Mr. Hillhouse has tried many types of sterns on the vessels he has designed, and I presume, from the figures given in the paper, that he considers the cruiser stern gives better results than any of the earlier types of stern.

No doubt Mr. Hillhouse has chosen the faster type of vessel for his example because it illustrates most markedly the advantages he states, and, although he has given a great deal of information, I think the paper would have been even more valuable if he had also touched on the application of the cruiser stern to the slower type of vessel to which such sterns are now very often fitted—I refer particularly to slow cargo vessels. It seems to me (especially for single-screw vessels on which it would generally be out of the water) that that type of stern would never satisfactorily replace the elliptical stern which has been in vogue in the past. I would like to ask Mr. Hillhouse his opinion of the cruiser type of stern for fast vessels, say for cross-channel steamers—compared with the design which has generally been followed. I refer to the design of the form in which the lines of the hull are carried aft to the back of the line of the rudder, as in the accompanying figure. With such a design it seems to me that he might be able to meet more easily Mr. Baker's ideals as to form, and, I believe, give some increase in hull efficiency.

Mr. John Anderson.

I am not prepared to make any definite statement regarding hull efficiency, but, from the analysis I have made of the results given by several vessels with cruiser sterns, and with the limited amount of data and facilities for analysis at my disposal, I came to the conclusion that there was a very distinct drop in this figure associated with cruiser sterns. Perhaps that was due to these vessels being very broad on the water-line in way of the propellers, and to the propellers being so far forward on the termination of the form.

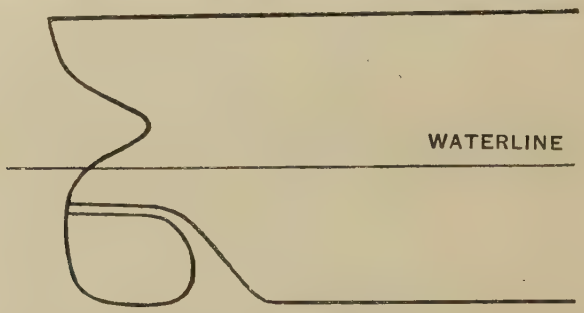


Fig. 14.

I would like to ask Mr. Hillhouse if he has considered the additional initial cost of fitting a cruiser stern to a vessel? It is necessary to adopt a very expensive type of rudder, and a considerable amount of extra steel is required. It appears to me possible, as an alternative, particularly in the slower types of vessels, to utilise some of this additional cost and weight by increasing the beam slightly instead of fitting the cruiser stern; in that way a finer model would also be obtained, and, in conjunction with the alternative type of stern to which I have referred, one would probably obtain as economical a result in propulsion as Mr. Hillhouse has suggested. With such a redistribution as this a great addition would be made to the cargo and passenger space in the middle (and best) portion of the vessel, as compared with that yielded by a cruiser stern.

Mr. Edward H. Parker.

Mr. Edward H. Parker (Secretary): Mr. Riddlesworth referred to the fact that about 20 years ago an attempt was made to design a cruiser stern for a merchant ship with the then existing type of propeller. I have here a model of a steamer on the straight-line principle with a cruiser stern which was made 25 years ago. A model of similar design was tried in the experimental tank at the Leven Shipyard, Dumbarton, by permission of Mr. (now Sir) Archibald Denny, and the results compared with those obtained with a model of the cargo steamer "Bhamo." That vessel was built by Messrs. William Denny and Brothers for Messrs. P. Henderson & Co. for their trade between this country and Burmah, and on her steam trials attained a speed of 11·8 knots.

The two models tried in the tank were each 12 feet in length, with the same breadth, draught, and displacement. The comparison showed that the two curves of resistance crossed each other at a speed corresponding to 11·5 knots. Above that speed the model with the cruiser stern was much better, and below somewhat worse than the model of ordinary design. It occurred to me at the time that further experiments on modifications of the after body of the model with the cruiser stern might have resulted finally in a much better performance.

Mr. P. A. Hillhouse, B.Sc. (Member): It is very interesting to hear Mr. Riddlesworth say that 20 years ago he had faced the problem of obtaining a satisfactory design, including both a cruiser stern and large propellers; he had, however, to give it up. To-day we are facing exactly the same difficulty; but now we are backed by precedent and tradition, and one of the strongest reasons that can possibly be adduced in shipbuilding for doing anything at all is that it was done before. As regards the relative length of overhang in the "Britannic" and the "Britannia," I have really not got the exact figures; but by scaling small published drawings I judge that the "Britannia," 305 feet long, had an 8 feet overhang; and in the same proportion the "Britannic," 850 feet long, would have an overhang of 22·3

Mr. P. A. Hillhouse, B.Sc.

feet. Actually she had 32 feet or about 40 per cent. more in proportion to length than the earlier vessel. I consider that overhang should be compared with height of counter above water instead of with length of ship, since, as far as appearance goes, it is the former relation that catches the eye and gives the impression of big or little overhang. Perhaps I was wrong in saying that the deception was innocent. I should perhaps say that people knew they were being deceived and rather liked it and just swallowed the deception.

Mr. Anderson speaks of the application of the cruiser stern to the slower cargo-vessel. I am sorry I cannot say very much about that, as my lines have not been cast much in the direction of full cargo-vessels. In that connection Mr. Hamilton's remarks are interesting, as he has dealt with this very point, and apparently finds an advantage in adopting the cruiser stern. Mr. Anderson referred to the stern of the "Empress of Britain." In her case the actual rudder was kept below water and the lines above it were carried aft of the stock to imitate the ordinary profile of the upper part of the rudder, as in Fig. 15, but the extension of the water-line amounted to about 7 feet only on a length of 550 feet, whereas with the cruiser stern about 20 feet can be obtained. With respect to hull efficiency, it is quite possible that the cruiser stern gives a little less hull efficiency than the ordinary type, and that may be largely due to the relation between the ship's section and the propeller. It is inadvisable to have a cross-section which "hugs" or overhangs the propeller too closely.

I have not gone closely into the relative cost of the cruiser stern and the ordinary stern; but very likely when you take into account the extra complication of the rudder, the cruiser stern would be somewhat more expensive. It is only a question of seeing whether the extra cost is justified by the benefits obtained. Mr. Anderson's suggestion that we should utilise some of the additional cost and weight by increasing the beam and so obtain a finer block coefficient is one worthy of consideration, and I

Mr. P. A. Hillhouse, B.Sc.

shall be very glad to look into it and see if I can find anything better than the cruiser stern in that way. As to Mr. Hamilton's description of the cruiser stern which he has adopted, I fancy that he has used the extension of the stern in a different way from what I suggested; that is to say, he has used the extension of the stern to increase capacity and increase displacement, and it is possible that this accounts for the fact that his results show only $1\frac{1}{2}$ per cent. advantage in propulsion instead of the 11 per cent. which I was bold enough to estimate in my paper.

Mr. Baker, in speaking here in February last, said that the principal advantage of the cruiser stern was just what Mr. Hamil-

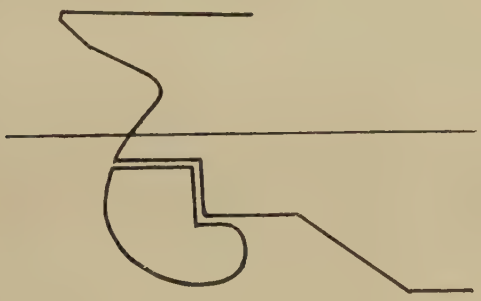


Fig. 15.

ton used it for, to ease the angle of run of the water-line, so as to avoid undue eddy-making about the stern. The cruiser stern fitted in that way is no doubt an advantage, stuck on as it were at the end of the ordinary ship; but my idea of the cruiser stern goes further; I believe that it should alter the ship from end to end, drawing out the displacement to a greater length, and that its effect should be felt right forward as well as aft. Taking a ship with the ordinary stern and fitting a cruiser stern, thus altering the after end only, the advantages of a finer run are obtained with more capacity and more displacement; but the effect, as far as propulsion goes, will not be so favourable as if the ship had been redesigned from the beginning with a single eye to propulsion. A cruiser stern can not be so advan-

Mr. P. A. Hillhouse, B.Sc.

tageously worked into a vessel having a single screw as it can be in the case of a twin-screw steamer. As Mr. Hamilton pointed out, the depth of immersion of the counter is only about 7 feet at load draught, and no advantage is secured at the lighter draughts. I have always fought shy of the cruiser stern with single screw, and usually advocate the ordinary stern in such cases. The possibility of adopting a cruiser stern is an additional argument in favour of a twin-screw installation as compared with that for a single screw.

Mr. Baker refers to the point which I mentioned in my paper regarding the angle of the water-lines aft and the great difficulty I had experienced in working in these water-lines so as not to exceed an angle of from 20 to 25 degrees, and I am pleased to see that Mr. Baker thinks that this is not perhaps a very vital point. He says that "His opinion is that this angle could be increased with advantage for cruiser sterns." I am pleased to hear that, because for some years my practice has been to make the stern angles a good deal fuller than 25 degrees, and, although I experienced no injurious results from that practice, yet I had a kind of uneasy feeling, after reading the paper read here by Messrs. Baker and Kemp, that it might have been a great deal better to have had a finer angle. Mr. Parker's model is of very great interest. It is often said that "there's nothing new under the sun," and here is a thing which we thought modern, and yet there is proof that it was thought of and dealt with not less than 25 years ago. This model is not that of a cargo boat merely, with the cruiser stern added, but it has some of the features of the straight-line vessels which have recently come prominently forward. Just how much of the difference in resistance between Mr. Parker's design and the ordinary cargo boat is due to the cruiser stern, and how much due to the straight lines forward, it is difficult to say. In making experiments of any kind it is of course advisable to have only one variable, because if two features are changed simultaneously it is extremely difficult to determine to which of the two features any difference in results is mainly attributable.

CALCULATING MACHINES.

By Dr. E. M. Horsburgh.

23rd December, 1919.

Historical Sketch.

Aids to calculation may be tabular, graphical, or mechanical. Among the mechanical aids are the calculating machines. These depend upon toothed gearing for performing the operations of arithmetic. There are other mechanical computing devices and instruments, such as slide rules, planimeters, integrometers, harmonic analysers, etc., but these are outside the scope of the above definition. However, in attempting to present even the crudest sketch of the development of the calculating machine, reference must be made to some devices which are not, strictly speaking, calculating machines, such as the abacus and the numbering rods of Napier.

Mechanical aids to computing have always been important, and are particularly so to the modern engineer, and to the commercial man. Ancient book-keeping, since it employed the Roman numerals, was a troublesome process, and some form of reckoner was even then a necessity. Its earliest form in classic days was probably the dust-board, a tray filled with moistened sand which could be scored by the fingers into a draught-board pattern. The squares could then be punched by the fingers with dots to represent numbers. Then pebbles (calculi) would be used as counters, and after that a more permanent form of calculator was made by stringing beads on wires.

In this way an instrument was formed with which it was possible to add and subtract, and even to multiply and divide,

without a knowledge of the classical theoretical arithmetic. This was the abacus, which has played so important a part in the practical or commercial arithmetic not only of the ancient and of the mediæval worlds, but also in the Far East at the present day. It is believed to have been invented independently among several different nations, and it has been in use, in one form or another, all over the world.

The arithmetic of mediæval Europe consisted of two parts—theoretical and practical. The former involved much that was mystical, and discussed the ratios and properties of numbers. This was elaborated originally by the Greeks, and handed down, imperfectly at first, through the writings of Boethius. This was the field of the professional mathematician. The latter (the practical arithmetic) dealt with calculation, and employed the abacus. The first stage of the abacus was the human hand, which even yet is not obsolete as a ready reckoner.

This form of practical arithmetic continued in Europe till long after the introduction of the Arabic numerals, and perhaps till near the beginning of the seventeenth century. Merchants kept their accounts in Roman numerals till as late as about 1550, and conservative universities and colleges did so for another century. Possibly this was why Chaucer's up-to-date Maunciple was so skilful in cheating his learned patrons. Incidentally we note that Shakespeare's clown in "The Winter's Tale" uses a kind of abacus.

In modern Europe the abacus is only used for teaching infants to count. In China and Japan, however, it is an important calculating device. These nations no doubt obtained it originally from India, into which country it had been introduced probably by some of the Semitic races, who were the great traders of the ancient world.

The swanpan or Chinese abacus is shown in Fig. 1. There is a strip which separates the beads into two groups of two and five. On any selected wire the five beads may each be taken to represent unity, and the pair of beads each represent five.

Charles Babbage
(*From an Early Photograph*).

John Napier

(From a Picture in the University of Edinburgh).

The wires on one side from this unit wire represent successively tens, hundreds, thousands, ... and on the other tenths, hundredths, ... so that a decimal notation is obtained in this manner. Thus the instrument gives a simple method of repre-

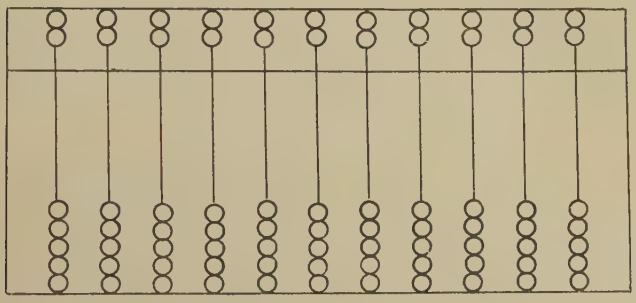


Fig. 1.

senting a number decimally. Thus Fig. 2 shows the number 37408 or any decimal variation of this sequence of digits, as the thumb might be used when holding the instrument to mark

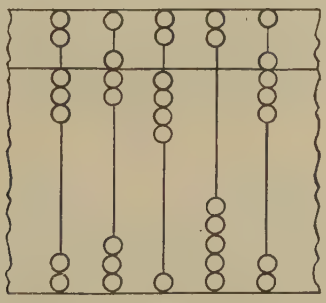
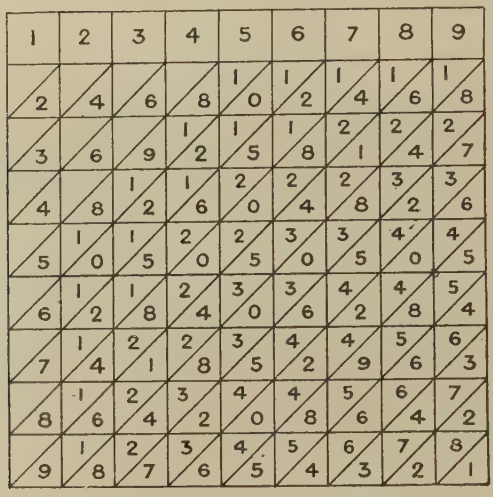


Fig. 2.

the position of the decimal point. The operations of addition and subtraction are self-evident. Those for multiplication and division are effected by learning a multiplication and division table extending only as far as nine by nine.

In the Japanese abacus or soroban, a single bead replaces the pair. The Russian abacus has a single group of ten beads on each wire, but variations of this occur, and in some places a duodecimal abacus is used. The Roman abacus was somewhat more complicated, as it dealt with Roman money.

Reference has been made to the difficulties which arose in attempting to carry out the operations of multiplication and division, even as recently as the later Middle Ages. Such work



1	2	3	4	5	6	7	8	9
2	4	6	8	10	12	14	16	18
3	6	9	12	15	18	21	24	27
4	8	12	16	20	24	28	32	36
5	10	15	20	25	30	35	40	45
6	12	18	24	30	36	42	48	54
7	14	21	28	35	42	49	56	63
8	16	24	32	40	48	56	64	72
9	18	27	36	45	54	63	72	81

Fig. 3.

was beyond the powers of all who were not skilled mathematicians. The fact that the discovery of logarithms, by John Napier of Merchiston, was made without the use of a symbolic notation to assist him is a startling testimony to his genius. The immortal " Mirifici Logarithmorum Canonis Descriptio " was published in 1614. By the use of logarithms the more complicated operations of multiplication and division were replaced by the relatively simple ones of addition and subtraction. In 1617 Napier invented his system of numbering rods or " bones,"

which give a more or less mechanical method of effecting multiplication. Each rod consists of the multiplication table for one of the numerals arranged in a vertical column, as in Fig. 3.

As an example, suppose that it be required to multiply 4185 by 752. Arrange the rods 4, 1, 8, and 5 in order, Fig. 4, setting on the right the rod which numbers the nine rows. Then the line of partial product 4185×2 is shown by the second row, *i.e.*, the numerals are in succession reading from right to left

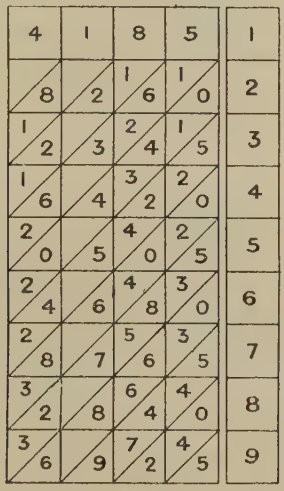


Fig. 4.

0, 1+6, 1+2, 0+8, *i.e.*, 8370. In the same way the partial product 4185×5 is shown by the fifth row, viz., 5, 2+0, 4+5, 0+0, 2, or 20925, and for the seventh row 29295. Hence, adding these lines of partial product as in ordinary multiplication we have 3147120. It will be observed that by the use of Napier's rods the labour of multiplication is replaced by the simpler process of addition.

8370
20925
29295

3147120

Napier's rods were of great practical value. To save time in selecting and arranging the "bones" a useful computer is formed when the numbers are inscribed on parallel horizontal cylinders, which by revolving can be set rapidly to the required factors. Such an arrangement for certain types of calculation can hold its own even at the present day. Fig. 5 is from an old print, and shows Napier operating his " bones."

The first true calculating machine, Fig. 6, was made by the famous mathematician Pascal, in 1642. It was constructed to help his father in statistical work. It forms the type from which the modern arithmometers may trace their descent. Suppose a wheel to have ten teeth inscribed respectively with the numbers 0, 1, 2 . . . . . 9, one of which is visible at a time through a dial or sight hole. Then if the number 2 were visible in this aperture, and the wheel were turned first through three steps or teeth, and afterwards through two steps, then the numbers 3 and 2 would be added to the original 2—that is, the sum of 7 would appear in the dial. If a train of such wheels could be constructed, with some arrangement suitable for "carrying" units when necessary, a calculating machine would be formed. Actually, of course, the numbers 0 . . . 9 are not inscribed on the teeth of the gear-wheels, but on discs parallel to and connected with them.

In Pascal's machine a peg was used, as is done in some of the modern cash reckoners, to bring a number indicated on such a wheel to a datum or zero position. By repeating this process the wheels were turned through amounts which summed the numbers chosen. For subtracting, the wheels had a second numbering, arranged in descending order, and visible through another aperture.

The defects of the early calculating machines were not in the principles employed, but were mechanical, and were due to the great difficulty of cutting a large number of gear-wheels sufficiently accurately to work together smoothly. In Pascal's machine pin-wheels of the simplest form were used for gearing

Fig. 5.—John Napier of Merchiston and his Numbering Rods.
From an Old Print.

Fig. 6.—Blaise Pascal (1623-1662) and his Calculating Machine.
(*From an Old Print*).

two shafts together at right angles, where at the present day bevel wheels would be employed. What strikes one particularly in looking at early calculating machines is the crudeness of the mechanism. This is not to be wondered at when one remembers that accurate machine tools only came into use about the middle of the nineteenth century.

The next important advance was the invention of a machine, containing a stepped reckoner, by the great mathematician Leibnitz. This in its later form consisted of a cylinder with nine teeth of the same height and breadth, but of different lengths, arranged round one quadrant of the cylinder, Fig. 11. By pushing an indicator or marker along a slot, a toothed pinion could be slid along a square axle, parallel to the axis of the cylinder, to gear with any number of these teeth from 0 to 9. Thus, if set by means of the marker to gear with five or three teeth, one revolution of the cylinder advanced the counting wheel through five or three teeth or steps respectively, and in this way adding could be performed by repetitions of the operation. This is the principle employed in modern arithmometers.

Leibnitz had the idea in 1671. His earliest model was made in 1694, and his principal machine was kept at first in Göttingen, and afterwards at Hanover. It was exhibited at the Academy of Paris, and at the Royal Society of London. It was defective, however, owing to the difficulty of cutting accurately the teeth of the wheels.

At an earlier date a British calculating machine had been brought out by Sir Samuel Moreland. This was dedicated to Charles II in 1666. It was for adding sums of English money. It is simple in construction, and the carrying mechanism is like that of a modern speed counter. Moreland also brought out a trigonometrical machine of a simple type. Another British machine of historic interest was made by James Bullock in 1775 for Viscount Mahon, afterwards third Earl Stanhope. It employed the stepped reckoner, and multiplication was performed by repeated addition, and division by repeated subtrac-

tion. A complete cycle, corresponding with a turn of the crank of a modern machine, was effected by moving a sliding rectangular frame to and from the operator for multiplication, and in the opposite sense for division. An improved form was brought out by the same maker in 1777, in which the "to-and-fro" motion was replaced by the rotation of a handle, cum-clock for addition and multiplication, counter-clock for subtraction and division. Other machines were made during the eighteenth century by Lépine, 1725; Leupold, 1727; Boistissaudeau, 1730; Gersten, 1735; and Pereire, 1750. The stepped reckoner was used by Hahn, 1774, and Müller, 1783. The date of the Thomas arithmometer was 1820, while the first keyboard machine was as late as 1861.

Before the end of the first quarter of the nineteenth century there was no calculating machine which could be called a commercial success. The first of which this could be said was an arithmometer made by Thomas, of Colmar, in Alsace, in 1820, and improved by Payen. It was manufactured extensively about the middle of the century, and is still used, though it is now looked on as old-fashioned. Most modern arithmometers differ little from it in general construction, though they may be modified considerably in details.

The Thomas machine was made in various sizes, but one of dimensions 27 inches by 7 inches by 3 inches can deal with products up to twenty digits. On the right is the operating handle; on the left a lever or regulator, which is pushed forward for addition and multiplication, and pulled back for subtraction and division. At the top is a movable slide, extending the whole length of the instrument, and containing a row of twenty dials for denoting sums and products. Below this is another row of dials for registering the number of turns of the operating handle. On the lower and fixed part of the instrument there is a row of slots, each marked with the numbers 0, ... 9, and there is a movable indicator or marker on each slot which can be set to any digit.

Thus any number can be set by these markers, and transferred by a turn of the handle to the top dials. If a second number be set by the indicators in the same way, and the handle turned, it is also transferred to the top dials, and added to the number already there. This carries out the operation of addition, while subtraction would be performed if the regulating lever had been pulled back.

To multiply, say, 8654 by 73, the number 8654 is set by the markers, the regulator pushed forward to addition or multiplication, and the handle turned three times. This adds 8654 three times, *i.e.*, multiplies it by three, and registers the result on the top or product dials. The three turns are registered by a 3 on one of the lower dials. The slide is then shifted one step to the right, and the handle turned seven times. The shift of the slide registers the product 8654×70, *i.e.*, in the proper place in the product dials, and adds it to the partial product already obtained, so giving 631742. At the same time 73 is now indicated on the lower dials as the multiplier.

For division the slide is moved to the extreme right, the dividend set on the top dials, and the divisor by the slot indicators. The regulating lever is pulled back to subtraction and division. Each turn of the operating handle then subtracts the divisor. This is continued till the divisor "won't go," *i.e.*, till the leading digits of the divisor exceed those of the dividend. The slide is then moved one step to the left, and the operation continued. The mechanism employed is referred to later. The Thomas machine is typical of the present-day group of arithmometers, and as such it leads to the consideration of modern calculating machines. See Figs. 8 and 11.

Before proceeding to examine these, a brief reference should be made to the differencing and the analytical engines of Charles Babbage. To these he devoted his life. They were, however, designed on too great a scale, and were never finished.

The differencing engine was for the mechanical construction of mathematical tables, such, for example, as occur in the

"Nautical Almanac." The principle on which it worked is easy to understand. Suppose we have any table, say of corresponding values of x and $f(x)$, as shown. Form the column of first differences, headed Δ, by subtracting in pairs the entries under $f(x)$, *i.e.*, $2197-1728=469$, so on. Treat this third column in the same way, viz., $547-469=78$, and so form the column of second differences, headed Δ^2. Treat this column in the same way and we get the column of third differences, Δ^3. In the present case these are of constant value 6.

If then, conversely, we are given the column Δ^3 and the first entry in each of the columns Δ^2, Δ, and $f(x)$—namely, the numbers 78, 469, and 1728—we can complete or reproduce the table for $f(x)$ by simple addition, *i.e.*, by reversing the above process.

x	$f(x)$	Δ	Δ^2	Δ^3
12	1728			
		469		
13	2197		78	
		547		6
14	2744		84	
		631		6
15	3375		90	
		721		6
16	4096		96	
		817		
17	4913			

Thus to complete the column Δ^2 we have $78+6=84$, $84+6=90$, and so on for the rest of the second difference column. Similarly $469+78=547$, etc., and in this way the column for first differences is computed, and then we get the required column for $f(x)$. Hence by this process $f(x)$ is tabulated by additions only. Thus Babbage's differencing engine was a glorified adding machine. It was intended to have six columns of differences, each of twenty figures. The design was such that the numbers

were arranged in vertical columns. Accordingly, to illustrate this by the previous example, if the machine were set to show

x	$f(x)$	Δ	Δ^2	Δ^3
1	1			
		4		
	7		7	
2		6		6
	2		8	
		9		
	8			

Then after one turn of the operating handle it would add in the manner indicated already, and there would appear the numbers

x	$f(x)$	Δ	Δ^2	Δ^3
1	2			
		5		
	1		8	
3		4		6
	9		4	
		7		
	7			

In this way the table would be completed, a new entry being obtained after each turn of the handle.

Babbage constructed a model of his machine in 1822, but by 1833 only a small portion of the main machine was completed. He had received Treasury grants as a help towards the expenses of construction, as the matter was considered to be of national importance. Latterly he ceased work on it, and finally it was abandoned by the Government in 1842.

George Scheutz, of Stockholm, followed in Babbage's footsteps, and succeeded in completing two much smaller differencing engines with three and four columns of differences respectively.

At the present day differencing engines such as these are scarcely necessary, as the same results can be obtained by a slight modification of some of the modern adding machines.

Babbage began his analytical engine in 1833, but by the time of his death, in 1871, only a comparatively small portion had been finished. The differencing and analytical engines were

very costly to construct, and though Babbage received State aid for the latter also, yet the expenses consumed also much of his private fortune.

The aim of the analytical engine was to carry out any sequence of arithmetical operations with any given numbers, and thus in fact to evaluate any algebraical formula. It consisted of three parts—the mill where the operations were performed, the store where the results were placed ready for use, and the controlling mechanism which directed the operations. The latter, which was, as it were, the brain of the machine, was of the nature of a Jacquard apparatus. It was worked by an arrangement of two sets of perforated cards—one for the mill and one for the store—which determined the operations, and specified their order. In this way numbers set up in the store were transferred to the mill, operated on there as required, and the values so obtained were returned to the store till the final result should be obtained.

A collection of historic calculating machines may be seen at the Museum of Science and Art at South Kensington. Among the exhibits are the machines of Moreland and Stanhope, the unfinished differencing engine of Babbage, that of Scheutz, and the incomplete analytical engine of Babbage.

For further information the reader is referred to "Le Calcul Mécanique" (Encyc. Sc.), by L. Jacob (Doin et Fils, Paris), and to "The Napier Tercentenary Handbook," Royal Society of Edinburgh (Ed. E. M. Horsburgh).

Modern Arithmetical Machines.

In attempting to give a very brief description of modern arithmetical machines, it is impossible to do more than indicate their general principles, as a detailed exposition even of a single machine would give rise to a lengthy pamphlet on that one subject alone.

The fundamental operation in a calculating machine is addition, since from this the others can be derived. Mechanical

addition involves two distinct processes, the summation of the digits, and the " carrying " from one denomination to another. These will be considered separately.

The summation of the digits is effected by one of five mechanisms—(1) the stepped reckoner, (2) the variable toothed wheel, (3) the circular rocking segment, (4) the reciprocating rack, and recently (5) by a double crown wheel. See Figs. 8 and 11, 17, 18, and 19, 22, and 27. Strictly speaking, (4) is a particular case of (3) when the radius of the segment becomes

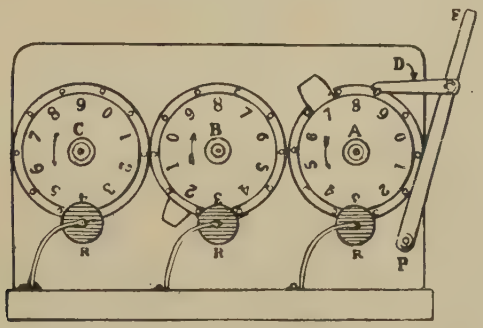


Fig. 7.—A Speed Counter.

infinite. These classify the arithmetical machines into different groups.

The operation of " carrying " is mechanically the most difficult, and the mechanism which controls it is the most delicate part of the machine. In its simplest form it is illustrated by the speed counter, Fig. 7.

Here, as the 9 in the units dial changes to 10, the 0 appears in the units dial in succession to the 9, while at that moment the projecting tooth on the units counting wheel engages with the tens counting wheel and moves it on by one step or unit. It is easily seen, however, that carrying in most arithmetical operations is more complicated than this, and to effect it some elaborate mechanism is required.

All calculating machines look extremely complicated, owing to the vast quantity of wheels and moving parts, but when any one of them is analysed it is seen to be built up of a large number of complete similar and similarly situated mechanisms, which may be likened to the cells of an organism. To analyse the machine is to study one of these cells.

Arithmometers.

These are developments from the Thomas machine which has been referred to already. An end elevation of this arithmometer

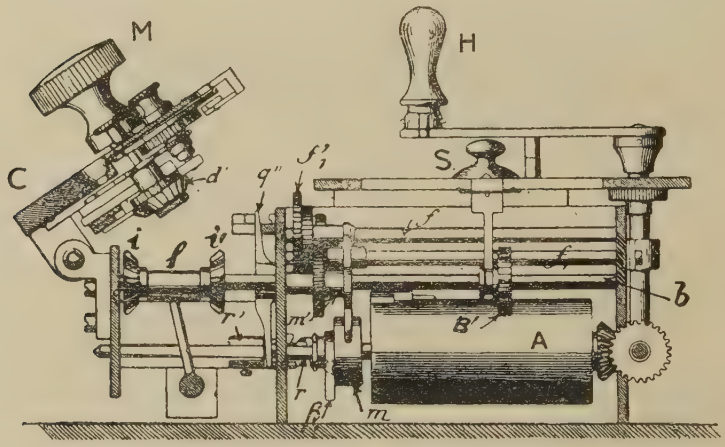


Fig. 8.—End Elevation of the Thomas de Colmar Arithmometer.

H—Handle. S—Marker. A—Stepped Reckoner. B′—Counting Pinion on Square Axle *b*, at the other end of which are the Bevel Wheels *i* and *i′* on a Sleeve giving the adding or subtracting rotations to the Bevel Wheel *d*, which works the Figure Disc in the Slide C (shown raised). M is a Milled Head which works the Effacer. The other letters show the carrying, numbering, and effacing mechanisms.

is shown in Fig. 8. The sliding carriage C is represented in a raised position. The handle H works the stepped reckoner A through bevel wheels. The marker S is set to a number on the indicator slot, and so causes the pinion B^1 to slide on its square axle *b* so as to engage with the corresponding number of teeth

on the reckoner A. When the carriage is lowered the wheel d^1 engages with the wheel i^1 on the sleeve I. Thus a turn of the crank handle H transfers the number set by the marker S to the upper dials in C, and so adds it to any number there already. If the regulator be pulled back to subtraction, the sleeve I is pulled back, so that i instead of i^1 engages at the other extremity of the diameter of d^1. This gives a negative rotation to d^1, and so subtracts from the number in the upper dials the number set by the markers S. Two milled heads M work a rack arrangement for clearing the digits from the dials.

A recent representative of this group is the "Archimedes," Fig. 9. The sliding carriage is seen at the top of the illustration, and the general features of the machine correspond with those of the Thomas. In the middle of the face of the instrument will be observed the row of slots, each with its column of numbers from 0 to 9, and furnished with the marker or indicator S, Fig. 8, which can be set to any digit. By adjusting these markers any number can be set. In some machines, as in the one under consideration, this number is also shown, for convenience, in control dials below the slots. On the left is the lever or regulator which sets the mechanism to addition and multiplication, or to subtraction and division. On the right is the handle which, by its rotation, operates the machine. Its axis is vertical, and the horizontal stepped reckoners are driven through bevel wheels. Above the row of slots, and on the slide, are two lines of dials, view holes, or apertures, one set of which registers the number of turns given by the handle for any position of the slide—*i.e.*, the multiplier in multiplication—and the other the product or the result of the operations. These machines employ the stepped reckoner, shown diagrammatically together with the essential parts of the mechanism in Figs. 8 and 11. The sliding carriage is shown in Fig. 10.

If a marker S, Fig. 8, be set at any digit, say 4, this causes to slide along a square axis a ten-toothed pinion wheel, so as

to engage with exactly four teeth on the stepped reckoner. By giving one turn to the operating handle the 4 is transferred to the result dial above the slot considered, and the one turn of the handle is duly marked. By moving the indicator to another digit, say 8, and again turning the handle, the number 8 is added to the 4. This gives a 2 in the units dial, while the 1 is "carried" and registered in the next higher view hole by the carrying mechanism. In this way by setting numbers by

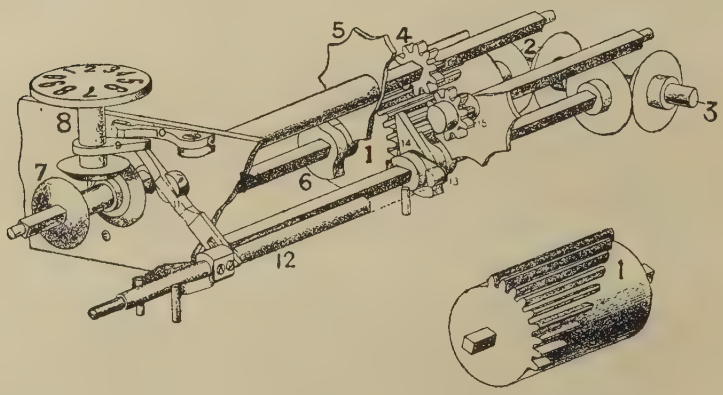


Fig. 11.—Diagrammatic View of Arithmometer.

1—Stepped Reckoner in position. 2—Bevel Wheels driven by the Shaft 3. 4—Sliding Pinion. 7 and 8—Bevel Wheels operating the Figure Disc. 9 to 14—Shows the "Carrying" Mechanism.

the markers, and turning the operating handle, they are added mechanically. The carrying is performed by an extra tooth, which slides into position at the critical moment, Figs. 8, β; 11, 14. Multiplication, being merely repeated addition, is carried out in the same manner. Thus, to multiply 864 by 531, set 864 by the markers. Give the handle one turn, and 864 appears in the product holes. Move the slide one space to the right, *i.e.*, into the tens place, and give three turns. Then move the slide one more space to the right and give five turns. The final result appears in the product holes, as the machine has added the suc-

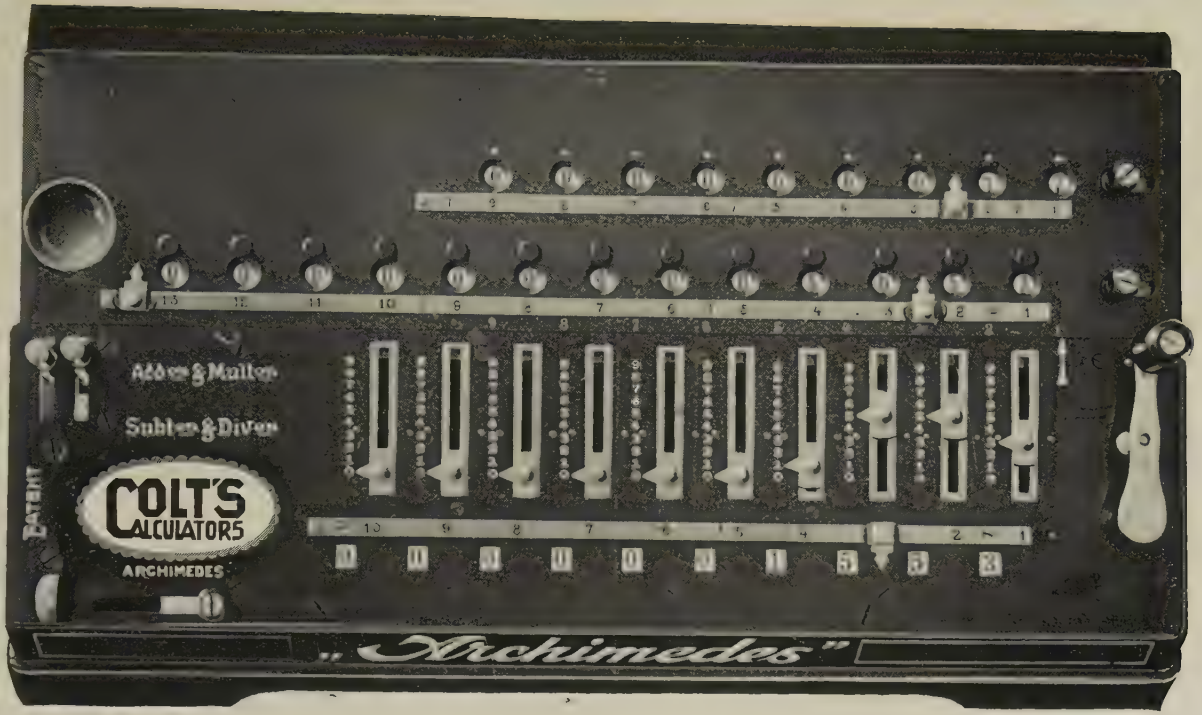


Fig. 9. Archimedes.

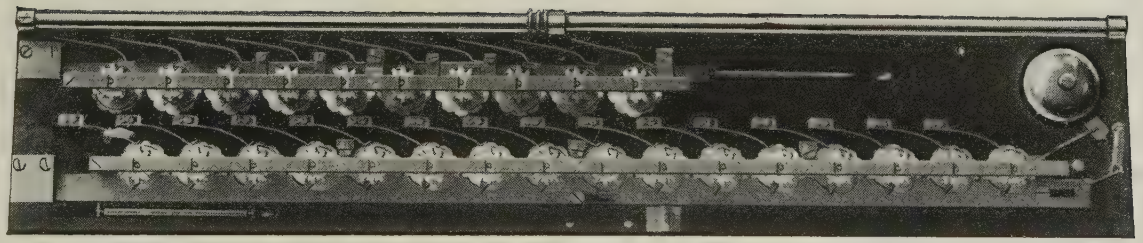


Fig. 10.—Sliding Carriage. (Arithmometer Type).

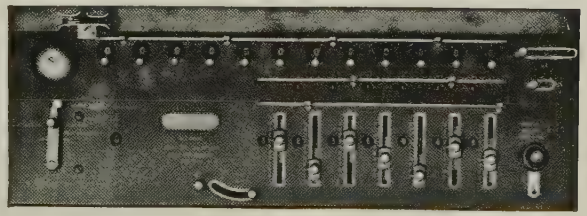


Fig. 12.—Madas.

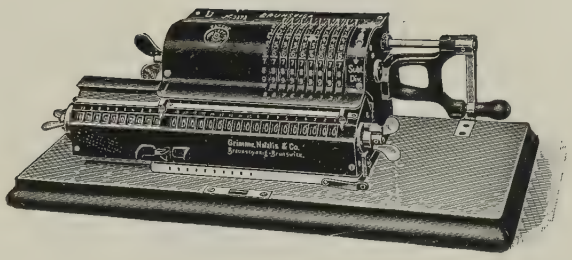


Fig. 13.—A Brunsviga.

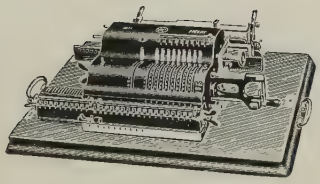


Fig. 14.—Brunsviga (small size).

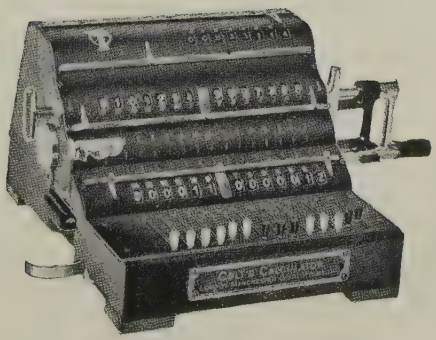


Fig. 15.—Colt's Calculator.

Fig. 16.—Colt's Calculator.

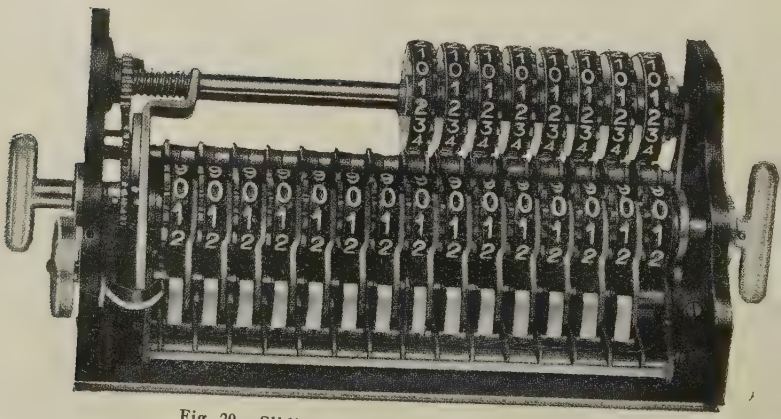


Fig. 20.—Sliding Carriage (Brunsviga Type).

cessive lines of partial product. What the machine has actually done is to replace the multiplication (A) by the additions (B).

		864	
864		864	
531		864	
———		864	
864		864	
2592	(A)	864	(B)
4320		864	
———		864	
458784		864	
		———	
		458784	

Since addition is obtained by the fundamental mathematical idea of a positive rotation of a counting wheel, the sequence of digits being 0, 1, 2 . . . 9, so subtraction is got by a negative rotation, the sequence being then 9, 8, . . . 0. Now when any wheel turns, the points at the ends of a diameter are moving in opposite directions. It could thus communicate an adding movement to a wheel gearing at one end of a diameter, and a subtracting movement to a wheel at the other end. Actually in the arithmometer two equal bevel wheels are keyed to the same axle, or rather sleeve, and so act as one wheel. See Figs. 8, i and i^1; and 11 (7). When this is pushed forward it engages and gives a positive rotation to the counting wheel d^1 which is carried by the slide and which lies between the bevel wheels. When the sleeves are pulled back by operating the regulating lever the negative rotation is obtained. In this way the shifting of the control lever changes from addition to subtraction, and conversely, in a very simple manner.

Division is performed by successive subtractions. The actual sequence of operations in division may be illustrated by dividing 9 by 7. The following scheme shows the successive subtractions:—

	9	20	60		40
	7	7	7		7
(1)	20	13	53		33
		7	7		7
		(2) 60	46		26
			7		7
			39		19
			7		7
			32		12
			7		7
			25	(5)	50
			7		
			18		
			7		
			11		
			7		
		(8)	40		

The slide with the dividend in its dials is pushed to the extreme right. The divisor is set by the slot markers. The slide is shifted by hand in the old machines, or automatically in the new, one place to the left after every step, and this is indicated by the introduction of the zero in the above scheme. The first four digits are seen to be 1·285 . . . . . and these are shown in the dials which register the number of turns of the operating handle. The remainder is on view at every stage.

A rack and pinion device is used for effacing the numbers in the view holes, and an arrangement of cams and springs for preventing over-running. This is shown in Figs. 8 and 10.

Among the older machines might be mentioned the Thomas

and the Tate, while among the newest are the Archimedes, Colt, Layton, Tim, Unitas, and Madas. The Madas, Fig. 12, is described among the automatic division machines.

The Brunsviga Group.

The idea of a wheel with movable pins or teeth was described by Poleni, of Venice, in his "Miscellaneis" in 1709. It appears next in a circular machine by Roth in 1841. In the second half of the nineteenth century a Swedish engineer, W. T. Odhner, employed this device in the construction of a successful calculator. His German patent was of the year 1891, and was acquired by the firm of Grimme Natalis & Co., Braunschweig. It is claimed by the Monroe Calculating Machine Co., N.Y., that Odhner saw in Europe one of Baldwin's American calculating machine models of 1875, and that Odhner thereafter patented a machine differing little in essentials, and that this was the origin of the "Brunsviga." The name "Brunsviga" has been applied widely to machines of this type. Since the expiry of the Odhner patents various other firms have produced modifications of this model, some of which are illustrated in Figs. 13-16.

The appearance of these machines differs widely from that of the arithmometers, as they are deeper, owing to their containing a large cylindrical counting barrel. They are also more compact. The axis of the operating handle is horizontal, not vertical, as in the arithmometers. The slots with their numbers and setting handles or markers are seen to be on the curved surface of the Brunsviga, and on the flat front parts of the two other illustrations. This special setting arrangement in the two latter diagrams enables the number, when set, to be read also in a line of view holes. The sliding carriage appears about the middle of the illustrations, and one form of it is shown in detail in Fig. 20.

The adding device is the wheel with a variable number of projecting fingers or teeth. It is formed by two discs, one con-

taining slots, Fig. 17, in which lie the steel fingers, and the other a thin covering disc, Fig. 18, which can turn about the former. Each finger, Fig. 19, has a projecting catch which lies in the groove *a* of the covering disc. If any digit, say 6, be set, the setting handle rotates the covering disc, and so moves the catches of six fingers through the crossing *b*, thereby pushing out those six fingers so as to make their ends project as teeth from the body of the wheel. If now the operating handle be

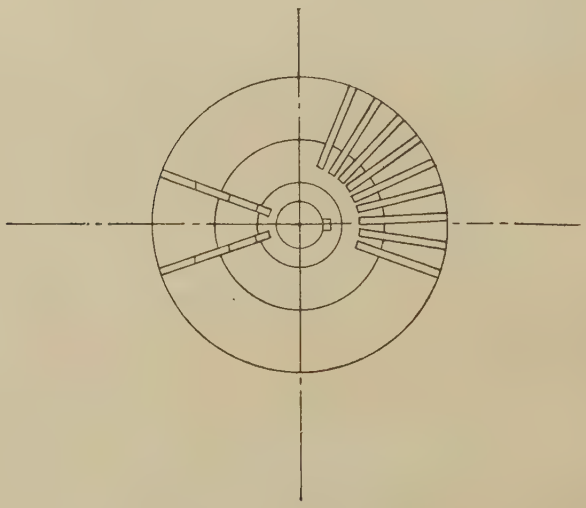


Fig. 17.—Disc of Adding Wheel.

turned the six teeth engage a counting wheel and turn it through six steps or units. Thus by this device the operations of arithmetic are carried out just as with the stepped reckoners of the arithmometers.

Accordingly, on setting any numbers by the slot markers, each revolution of the operating handle transfers them to the result dials, where they are added to any numbers already there. Multiplication is carried out as a repeated addition, as with the arithmometer.

For subtraction the required rotation, being negative, is got directly in a very handy fashion, merely by turning the operating handle in the opposite direction. Division, too, is obtained by repeated subtraction, as with the arithmometers. The value of being able to perform additions and subtractions by positive

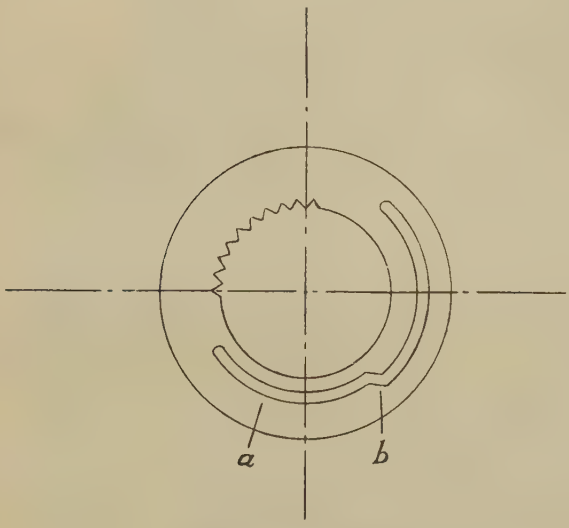


Fig. 18.—Cover Disc.

or negative turns of the handle is very evident, and a further advantage lies in the fact that as the variable toothed wheel can be made extremely narrow, the slots lie close together, and the eye has not to survey a great area to pick up a large number. This produces compactness of form.

Fig. 19.—Brunsviga "Finger."

If a turn too many be given at any stage in division a bell rings, and the error may be eliminated by giving a positive turn to the handle. This makes the operation of division nearly

automatic. The effacing of results is carried out by an ingenious butterfly nut arrangement, which, by a helical movement, sets all the counters to zero.

Recent improvements on the original Odhner machines include the control dials, setting levers, and printing devices, which may be seen in the diagrams. These machines are very convenient to work, and are easy to transport.

Other machines of this group are the Triumphator, Teetzmann, Muldivo, and Marchant.

The Adding Machines.

Those machines which are essentially for adding and listing are worked by means of keys like a typewriter. Other calculating machines too, however, are now being fitted with keys, so as to render them more convenient for the commercial operator. The use of a keyboard with a calculating machine was first introduced in a model put on the London market in 1861 by V. Schilt. The fundamental device employed by modern adding machines is the toothed sector, or sectorial rack.

The general appearance of a well-known form of a Burroughs adding and listing machine is shown in Fig. 21. This illustrates the relative positions of the printing arrangements, dashpot, racks, guides, stop-wires, and operating handle. The subsequent illustrations show the details.

Reference to the diagram, Fig. 22, shows that when a key, such as number five, is depressed it moves by means of a bell-crank lever F, a stop-wire pulling its end inwards, which limits and specifies the travel of the toothed sector B. This toothed segmental rack B is carried by the pivoted lever A, engages the number-wheel C when required, and moves between the guide-plates D. The rack descends through the specified number of teeth—five in this case—and the corresponding type for printing, carried at the other end of the pivoted lever A, comes into position, and is struck by a hammer and printed. See Fig. 23. During the descent the counting wheel is thrown out

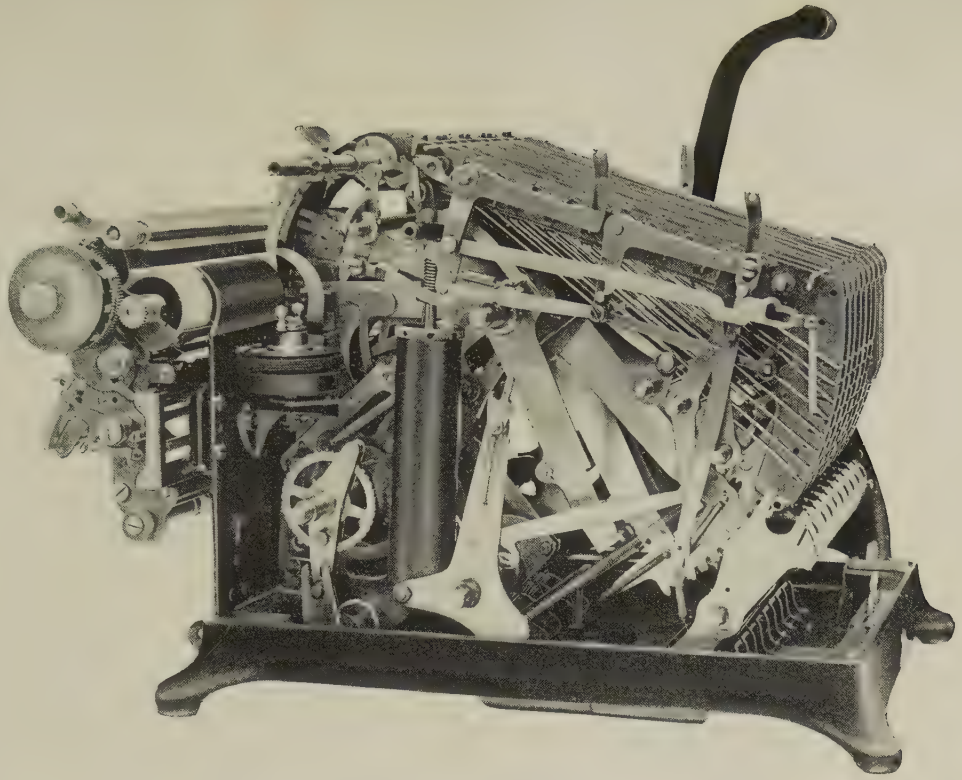


Fig. 21.—Burrough's Adding Machine (Cover Removed).

of gear, but on the ascent it engages, and is turned through the number of teeth specified by the key. By repeating this operation the adding of any numbers is performed.

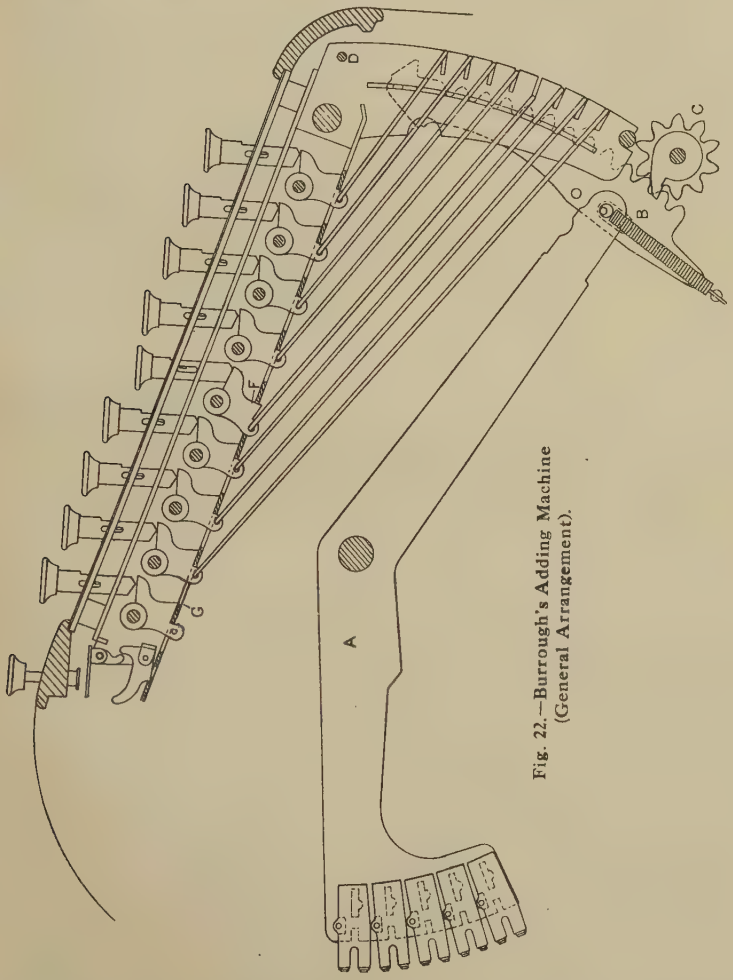


Fig. 22.—Burrough's Adding Machine (General Arrangement).

For " carrying," a stop is released which allows the next rack to ascend one step higher than normal. This communicates the additional unit to the required counting wheel.

If then a set of racks and counting wheels is arranged in series in this fashion, possessing the necessary carrying apparatus, an adding machine is formed, and the number wheels will show

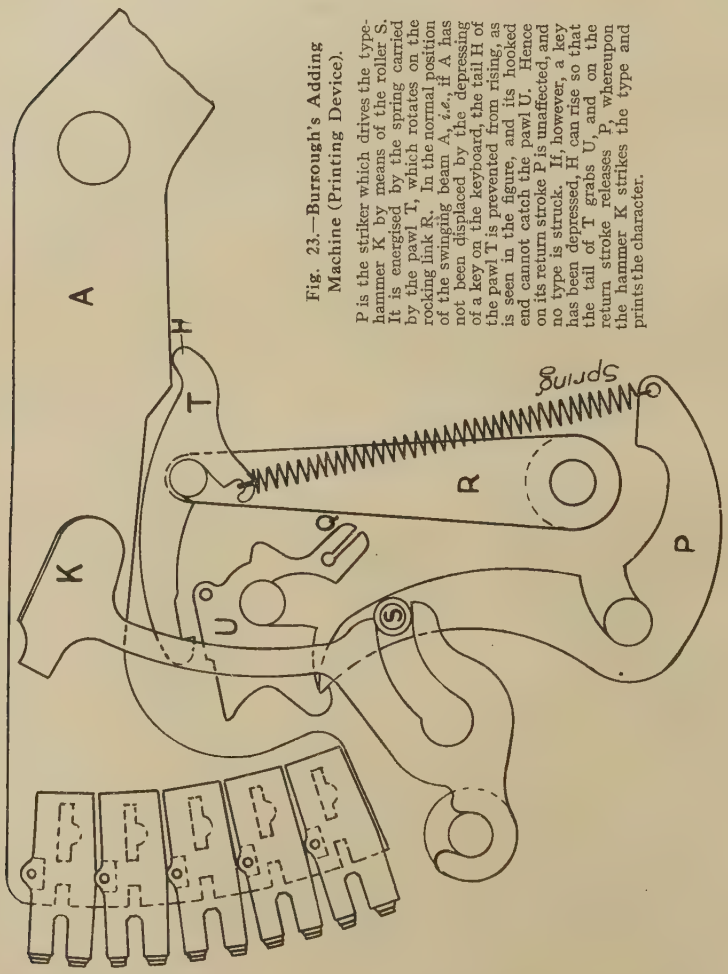


Fig. 23.—Burrough's Adding Machine (Printing Device).

P is the striker which drives the type-hammer K by means of the roller S. It is energised by the spring carried by the pawl T, which rotates on the rocking link R. In the normal position of the swinging beam A, *i.e.*, if A has not been displaced by the depressing of a key on the keyboard, the tail H of the pawl T is prevented from rising, as is seen in the figure, and its hooked end cannot catch the pawl U. Hence on its return stroke P is unaffected, and no type is struck. If, however, a key has been depressed, H can rise so that the tail of T grabs U, and on the return stroke releases P, whereupon the hammer K strikes the type and prints the character.

at any time the total of the figures printed successively on the paper. In order to print the sum total, a "totalising" key is depressed. Its action is to keep, during the first part of the

movement, the counting wheels in gear with the sectors, which then descend as far as the numbers registered on the wheels permit them. The types for printing the total are then in the position for printing, and are struck. The counting wheels have thus been moved back to zero, so are thrown out of gear as the racks are raised. Thus the taking of a total clears the machine, *i.e.*, sets all the number wheels to zero.

Energy is supplied through the operating handle by means of springs, Fig. 24, so that a careless operator cannot overstrain the mechanism. A dashpot, too, is employed, Fig. 21, to give steadiness in working. Many safeguards have been introduced, one of which is that the striking of a key prevents the accidental depression of another key in the same column. A simple method whereby this result is obtained is shown in Fig. 22, where the movement of the bell-crank F displaces the sliding-plate G, and so locks every other key in this column.

Subtraction is carried out by adding the complementary number. The latter may be defined by saying that any number plus its complement forms some whole multiple of ten. Thus 7 and 3 are complementary. For subtraction the complementary numbers are marked on the keys in small type. In most cases it is more convenient to take the complement with respect to 9 instead of 10, and in that case a special mechanism adds unity to the result. Thus instead of subtracting 764 from 876 and obtaining 112, we may add $876+235+1=(1)112$ and so obtain the same value.

Multiplications and divisions are accomplished as repeated additions and subtractions respectively, but the "typist" touch for doing this rapidly requires a certain amount of training.

Many of the component parts of the adding machines are of extremely complicated shapes, as may be seen from the diagrams. The Comptometers and small Burroughs calculators are widely known and greatly used. They are extremely compact, and work on the same general principles as the larger machines. The cash registers also belong to this group.

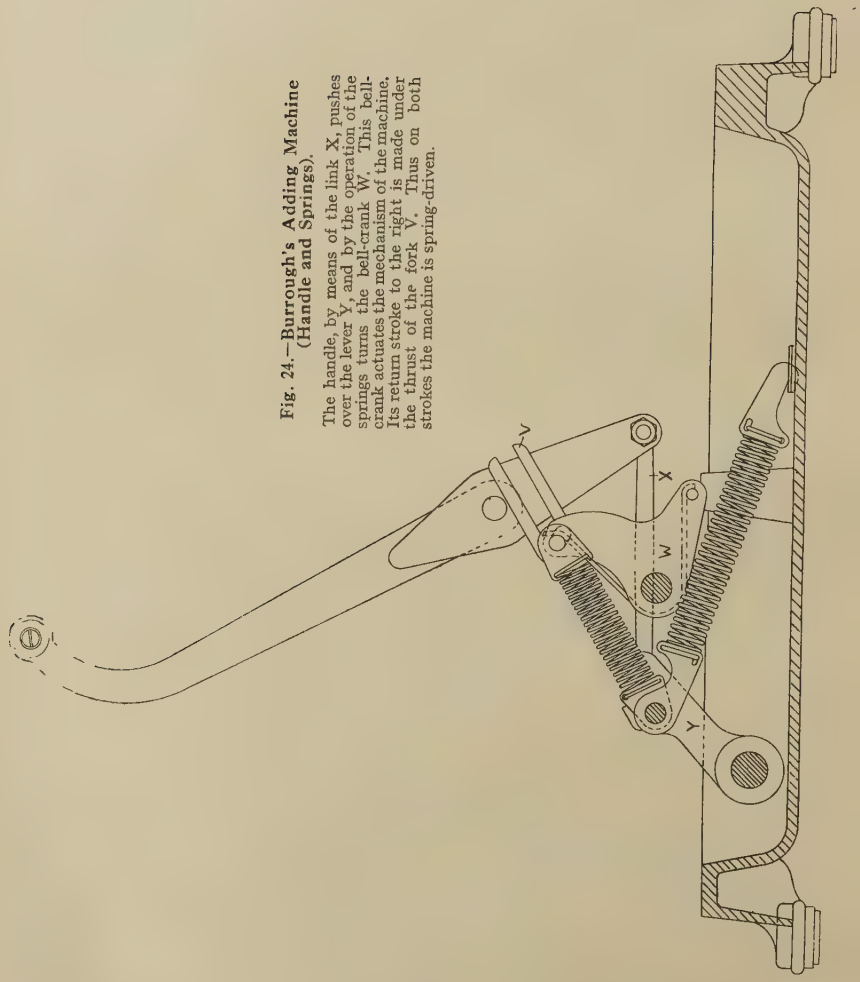


Fig. 24.—Burrough's Adding Machine (Handle and Springs).

The handle, by means of the link X, pushes over the lever Y, and by the operation of the springs turns the bell-crank W. This bell-crank actuates the mechanism of the machine. Its return stroke to the right is made under the thrust of the fork V. Thus on both strokes the machine is spring-driven.

Recent improvements are many, and have been devoted to equipping the adding group for all kinds of commercial work. This is particularly noticeable in the newest and largest Burroughs adding and listing machines. Instead of having a single counting wheel for each rack, there is a wheel gearing with two in mesh, set to give complementary numbers. This affords a rapid method of adding or subtracting by taking the result from either of the complementary wheels. It also enables two, three, or four groups of items to be summed simultaneously in one column. Summations may also be effected in line. It is needless to say that these arrangements are extremely valuable in book-keeping and accounting. Also by depressing any one of a row of stops at the top of the keyboard the latter may be split wherever required, so as to give various separate machines. Devices for removing immediately a wrong entry have also been introduced. Further, by adjusting the positions of rollers on a controlling bar the columns of items may be printed wherever required on a sheet of paper. It will be seen that these commercial machines, which are thus adaptable to all sorts of business requirements, are more highly specialised than those which are required by the mathematician, though their fundamental principles are the same.

The mathematical and calculating typewriters may also be included under this section. An instrument able not only to type all ordinary correspondence, but capable at the same time of adding, subtracting, and listing the various items, is of such use in business that any comment upon its utility would be superfluous. Such machines are now made by various typewriter companies. In many cases the arithmetical mechanism is attached to an ordinary correspondence typewriter. The Monarch Wahl instrument may be selected as an illustration of this class. Its computing mechanism consists of two parts, called respectively an actuator and a totaliser. The typewriter prints any number in the usual way when the keys are struck. The actuator mechanism lies in the front of the machine, and

is connected with the key levers which operate the bars carrying the figures. The motion of any such bar when moved is communicated by the actuator to a universal gear wheel. Hence when keys 1, 2, 3, . . . are depressed the universal gear wheel moves 1, 2, 3, ... teeth respectively.

The totaliser, a small adding box, whose function is to sum the numbers typed, is carried on a truck immediately above the actuator, and is furnished with gears which can engage those of the universal gear of the actuator. The totaliser moves with the carriage. When it comes to the position on the paper where the machine is typing a number in a list, it picks up from the actuator this item by having its own counting wheels pushed by the stops or studs which are engaged, and so it adds the last item to what has already been recorded. In this way it sums all that has been printed. This total also may be printed by the operator, or in some cases it is struck automatically. The mechanism may also be reversed by the touch of a key, whereupon the machine will subtract.

There are various safeguards to prevent improper operation. Thus, if the totaliser be removed from the bar to which it is attached, its wheels become locked automatically, and cannot be moved till the totaliser is replaced. The carriage, too, travels automatically to the correct column when the corresponding key is depressed. If a key does not complete its stroke, the machine locks till the error is rectified. A two-coloured printing ribbon is used if required, so as to distinguish the additions from the subtractions.

The new Elliott-Fisher adding machines embody these principles. Their totalisers or adding boxes, however, are clamped to a fixed bar, and are set where the columns of figures in a large sheet of paper are required to be. In this case the same relative motion is obtained by the movement of the keyboard. While doing so it types the written communication, and at the same time prints and totalises each column of figures as required. These machines accordingly differ widely in appearance

from any of what may be called the Burroughs group of adding machines.

In the illustration, Fig. 25, the large fixed sheet of paper is seen in front, and the arrangement whereby the machine moves over it is shown. The standard keyboard, and above it the adding mechanism, are on the left. These together traverse the frame, and in doing so pass in front of the adding registers, shown at the top of the diagram. On the right of the standard keyboard is the automatic tabulator. The adding registers are seen clamped on their bar wherever required, and as the keyboard traverses the frame the gear engages successively with the studs of each register, and so effects the adding.

Incidentally it might be mentioned that there are some typewriters which can print practically all the mathematical symbols. In most cases there are special keys for these. The Hammond Typewriter Co., however, employs a rapidly interchangeable device. This consists of cylinders on which the types or symbols are cast, all in one piece, as in a printing machine. The paper is struck from behind against the type, and, as the type cylinders are rapidly interchangeable, it is possible for the operator to type mathematical papers in any language.

Other adding machines include the Barratt, Victor, Mechanical Accountant, and among listing machines the Dalton, Federal, Sundstrand, Teetor, and Wales.

The Millionaire.

The Millionaire was patented by O. Steiger, and is manufactured by H. Egli, in Zurich. It performs the operations of arithmetic, and is a specialist in multiplication. This it does not accomplish by repeated additions, as with the machines already mentioned, but it may be said "to know," mechanically, the multiplication table. Hence it forms a class by itself. It multiplies by any digit by a single turn of the handle, which makes it very convenient to operate.

In the general diagram, Fig. 26, K is the crank or operating

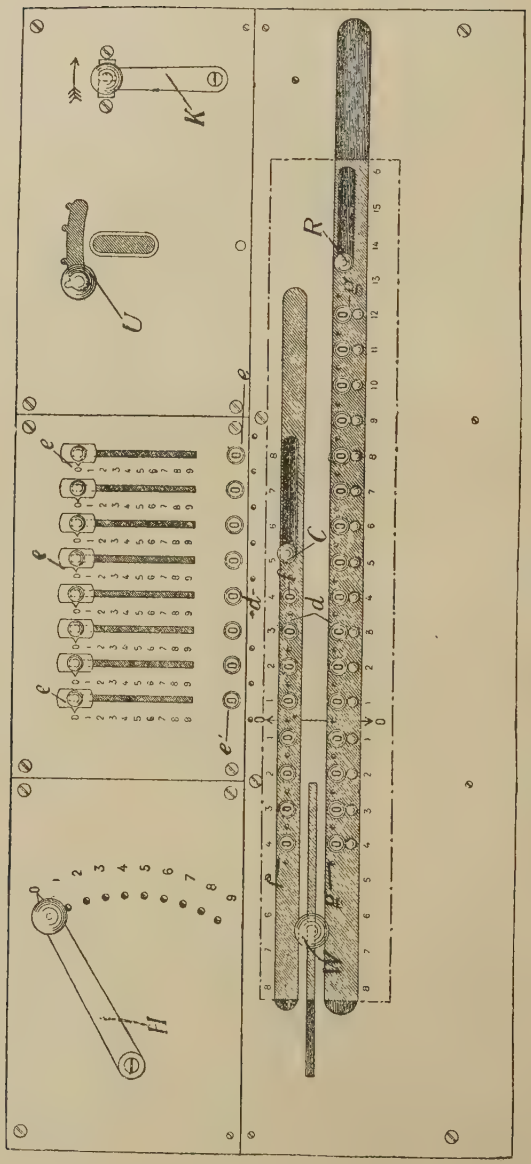


Fig. 26.—The Millionaire. Diagram showing General View.

handle, U the regulator for setting to addition, subtraction, multiplication, or division. The slots and their indicators or markers are shown at *e*, and their control dials at e^1. The view holes *f* give the multiplier or quotient, and the result dials are at *g*. Corresponding positions are shown at *d*. H is the multiplication lever, which is set, say, at 8, Fig. 28, in order to multiply by 8. R and C are effacers, and W shifts the carriage, Fig. 26, and works the recorder or registering apparatus.

Similar lettering is shown in Figs. 27 and 28. B and S in Fig. 27 indicate diagrammatically the linking to the tongue-plates at C of the racks Z, which are shown in gear with the counting pinions T. In Fig. 28 the bevel wheels R transfer to the recorder the rotations of the pinions T, which are obtained from the longitudinal motions of the racks.

In simple addition or subtraction the multiplication lever H is set to unity. Division may be worked directly, but a very handy way is to use tables of reciprocals, and then to operate by multiplication.

Perhaps the most striking feature of the mechanism is a set of nine tongue-plates or multiplying pieces, Fig 27a. These represent by their lengths the multiplication table, as is shown clearly by the diagram. Thus the number 6 on rack 7 indicates $6 \times 7 = 42$, which is represented by four units of length on the "tens" tongue (shown hatched), and two on the units tongue (white). The counting gear consists of straight racks with pinions. The setting of the multiplication lever H to any digit, say 8, Fig. 28, puts the tongue-plate 8 in the position for working. The straight horizontal toothed racks rest against the tongues, and are displaced by them in working by the length of the tongues. This displacement moves the counting wheels of the recorder, which are geared with the racks, through the corresponding number of steps or units, Fig. 28. This is done during the forward movement of the racks. Actually the "tens" tongues operate first, and the counting mechanism is

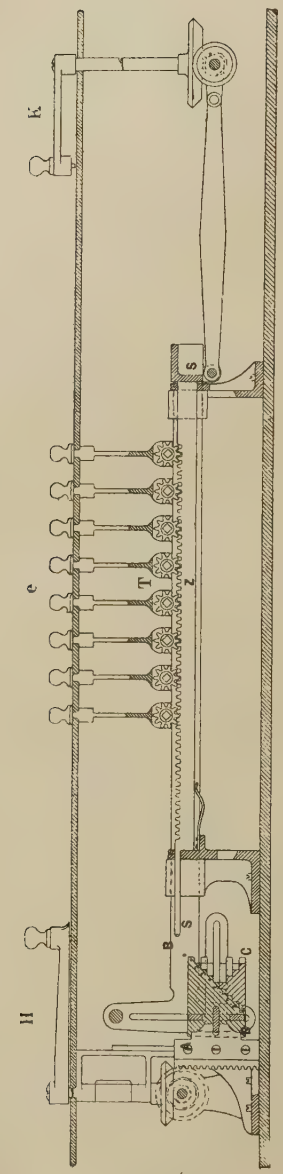


Fig. 27.—The Millionaire. Elevation, showing Racks, Tongue-Plate, and Counting Mechanism.

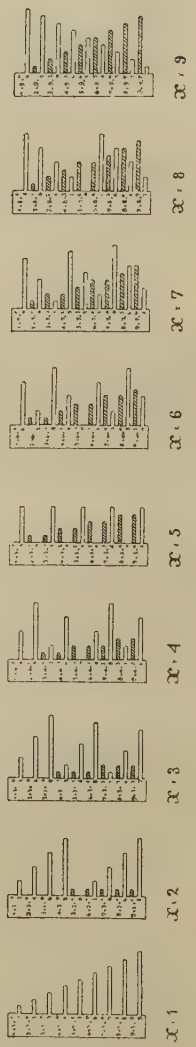


Fig. 27a.—The Tongue-Plates.

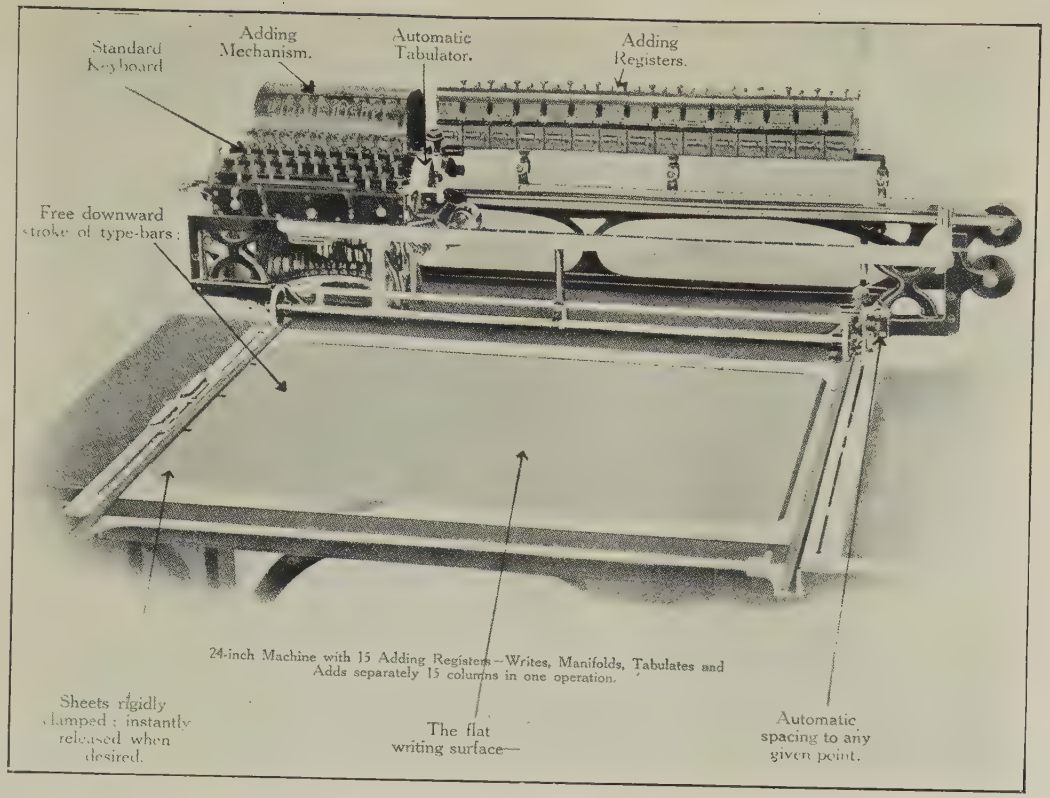

Standard Keyboard
Adding Mechanism.
Automatic Tabulator.
Adding Registers.
Free downward stroke of type-bars.
24-inch Machine with 15 Adding Registers—Writes, Manifolds, Tabulates and Adds separately 15 columns in one operation.
Sheets rigidly clamped; instantly released when desired.
The flat writing surface—
Automatic spacing to any given point.

Fig. 25.—The Elliott-Fisher Machine

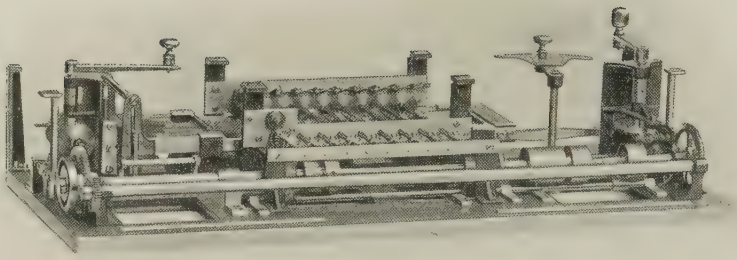


Fig. 29.—Millionaire. General View of Mechanism.

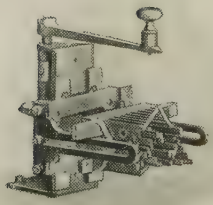


Fig. 30.—Millionaire. Handle and Tongue-Plates.

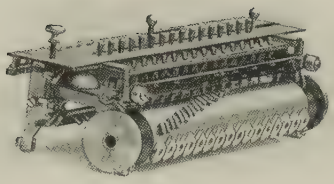


Fig. 31.—Millionaire. The Carriage.

Fig. 32.—Millionaire fitted with Keyboard, and on a Stand suitable for an Electric Drive.

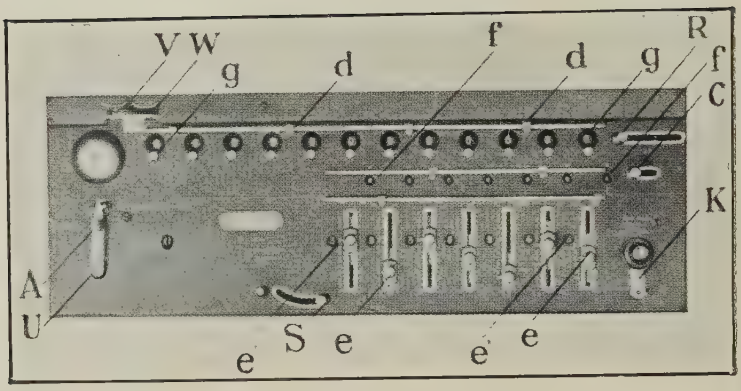


Fig. 34.—Madas Calculating Machine.

Fig. 35.—Monroe Calculating Machine.

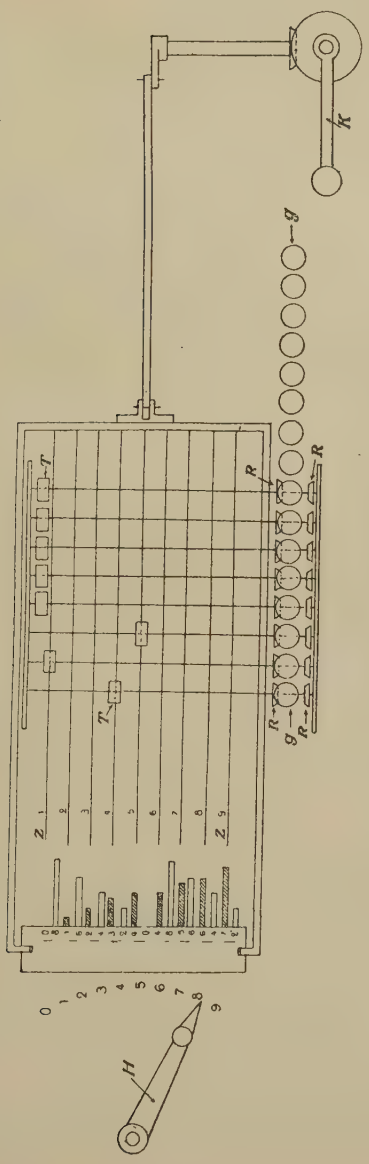


Fig. 28.—The Millionaire. Plan showing Counting Mechanism.

displaced automatically one step to the left, so that for the next stage of the work, when the "units" tongues operate, their result is in its proper place. Accordingly when the machine multiplies, say 416 by 8, we have the scheme—

$$4,\ 1,\ 6, \times 8 = 32,\ 08,\ 48.$$

i.e., 3, 0, 4
2, 8, 8

3, 2, 12, 8 *i.e.*, 3328.

Actually the mechanical process is highly complicated, as in a single turn of the handle no less than twelve distinct mechanical operations are carried out. While this gives a hint of the marvellous mechanism and the complicated structure of the Millionaire, this perfection of fitting referred to may be said to apply to all the calculating machines of the present day.

Fig. 29 shows a general view of the machine when the cover is removed. The parts can be recognised from the earlier diagrams. The crank is shown in Fig. 30 and the carriage in Fig. 31. Fig. 32 shows a large size Millionaire fitted with a keyboard, and on a stand suitable for working with an electric motor.

Machines in which the Division Operation is Automatic.

Division is the most troublesome of the simple rules, and even with the ordinary arithmetical machines this operation requires a certain amount of watching. The most characteristic property of the Mercedes-Euklid and Madas machines is that they render division purely automatic.

The Mercedes-Euklid resembles an arithmometer in appearance, but employs a different principle. It bears a strong outer esemblance to the Madas, shown in Figs. 11 and 34. The Madas

is a recent and improved arithmometer. Accordingly, what has been said of the general appearance and operating of the arithmometer applies equally to these machines, and attention will be drawn chiefly to those matters which involve differences or improvements. Addition, subtraction, and multiplication are carried out by the operator in the ordinary way. For automatic division the dividend and divisor are set by means of the row of result dials and the slot indicators or markers. The sliding carriage is pushed to the extreme right, as in ordinary division. On the left of the Mercedes-Euklid are two studs or controls, which may be pushed forward or backward, so locking and unlocking the operating handle in one or other position. In working, the operating crank is turned till it locks, then the studs are pushed over, the carriage moves back a step, and the handle being released is turned till it locks again, and this sequence is repeated. By fitting on a small electric motor even this is done automatically. Numbers flash through the dials like a torrent of water pouring down a cascade. In two or three seconds the machine suddenly stops, and, as if by magic, the quotient and remainder are on view.

The Mercedes-Euklid machine was designed by Ch. Hamann, of Friedenau, Berlin. Its adding mechanism employs the straight rack and pinion. In this case there are ten parallel racks, one to correspond with each of the horizontal rows of figures 0, 1, . . . 9, extending from slot to slot. The displacements of the racks, which must be proportional to these digits, are obtained by the elegantly simple device of a proportional lever. The racks gear with pinions, which communicate their movements to the wheels of the recorder.

The slot mechanism of the Mercedes-Euklid is shown in Fig. 33. The horizontal lines Z_0 to Z_9 represent the ten horizontal straight racks, linked to the proportional lever H. The vertical lines indicate diagrammatically the slots, and also the square axles A on which slide the counting wheels R. The proportional lever may be made to rock about either end X or X_1, and is

moved by the crank or handle K through the connecting rod *pl*. If as in the figure the proportional lever works about the

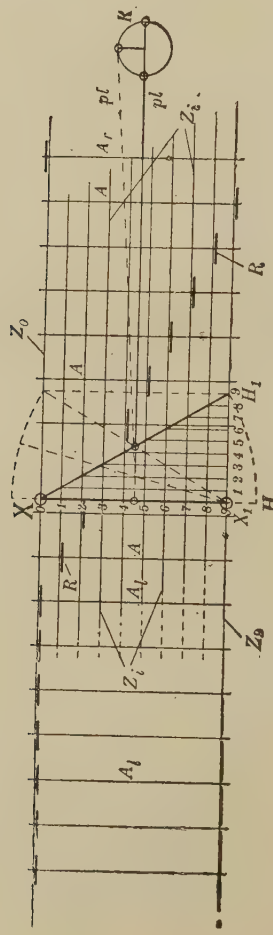


Fig. 33.—Diagram of the Action of the Mercedes-Euklid Machine.

point X, then by similar triangles the racks Z_0, Z_1, . . . Z_9 get displacements respectively 0, 1, 2 . . . . 9, *i.e.*, the counting

wheels, set by the markers to any numbers, identical of course with the numbers of the racks, get rotated by the amounts of those numbers. In other words, when a slot marker is set, say to 3, the first turn of the crank will move all the racks about X except Z_0, and hence the corresponding counting wheel of the third rack is advanced through three steps or teeth. By repetition of this movement adding is accomplished.

The subtracting device is particularly ingenious. The proportional lever H is then pivoted about its other end X_1, and so, by similar triangles, displaces the racks again, in a proportional manner, and this time each movement gives a complementary number to the former value, Fig. 33 (dotted lines). The addition of these complementary numbers produces the required subtraction.

The operation of automatic division on this machine can now be understood. It begins by successive subtractions of the divisor, *i.e.*, by adding the complement of this number till this is carried a step too far, which is shown by the handle becoming locked. The stud or control is released, and the carriage shifts a step for the next figure of the quotient, while the handle now adds the divisor at each turn, till locking occurs again. This sequence is then repeated, and in this way the quotient is obtained figure by figure. It will be observed that at each stage the machine produces approximations, successively greater and less than the value required. These converge continually upon the quotient as their limit value.

As an example of the action of the machine, consider the steps which occur in the automatic division of 20 by 7. The following scheme makes these clear. L shows where the machine locks. $Q_1, Q_2, Q_3, \ldots\ldots$ stand for the first, second, third $\ldots\ldots$ approximations to the value of the quotient Q. The operations begin by subtracting 7, *i.e.*, by adding the complement 93. The successive turns of the crank are shown to the left of the additions. The additional zero shows where the carriage moves.

	20
(1)	93
	113
(2)	93
	206
(3)	93
L	(2) 990

$Q_1 = 3$

	990
(1)	7
	997
(2)	7
L	(1) 0040

$Q_2 = 30 - 2$
$= 28$

	0040
(1)	9993
	10033
(2)	9993
	20026
(3)	9993
	30019
(4)	9993
	40012
(5)	9993
	50005
(6)	9993
L	(5) 99980

$Q_3 = 280 + 6$
$= 286$

	99980
(1)	7
	99987
(2)	7
	99994
(3)	7
L	(1) 000010

$Q_4 = 2860 - 3$
$= 2857$

	000010
(1)	999993
	1000003
(2)	999993
L	(1) 9999960

$Q_5 = 28570 + 2$
$= 28572$

	9999960
(1)	7
	9999967
(2)	7
	9999974
(3)	7
	9999981
(4)	7
	9999988
(5)	7
	9999995
(6)	7
L	(1) 00000020

$Q_6 = 285720 - 6$
$= 285714$

	00000020
(1)	99999993
	100000013
(2)	99999993
	200000006
(3)	99999993
L	(2) 999999990

$Q_7 = 2857140 + 3$
$= 2857143$

	999999990
(1)	7
	999999997
(2)	7
L	(1) 000000004

$Q_8 = 28571430 - 2$
$= 28571428$

Thus the quotient to an 8 figure value is 2·8571428 The successive convergents to this value will be noticed. They are 3, 2·8, 2·86, 2·857, 2·8572, 2·85714, 2·857143, 2·8571428, which are alternately greater and less than the value sought.

The Madas is shown in Figs. 11 and 34. K is the crank or

operating handle, U the regulator for setting to addition, subtraction, multiplication, or division. W and V are carriage shifters, complete or single step, the carriage being at the top of the illustration. The markers or slot indicators are shown at e, while e^1 shows the control numbers. S, R, and C are the effacers. The result dials, used also for dividends, are at g, while the multiplier and quotient dials are at f.

As already mentioned, the Madas is an arithmometer, and so employs the stepped reckoner. In dividing, with one of the early arithmometers, such as the Thomas, care must be taken, as has been pointed out already, that the subtractions are not carried a step too far. If, however, this were done a row of nines would appear in the product holes, and a slight jar would be felt in the mechanism. Accordingly it would be possible that a stop should be interposed instead of setting up the nines. This then would occur when the subtracting stage had been carried as far as permissible. The carriage would now require to slide one step to the left, and then the subtracting operation would be resumed. By introducing some such stop, with a release to shift the carriage one step to the left, automatic division could be effected. The operations are carried out by successive direct subtractions, and are illustrated on page 134.

In working the Madas the operating handle is pushed down against a spring before being rotated. The effect of the push is to displace the bar which works the sleeves already spoken of as carrying the bevel wheels, which rotate positively or negatively the counting wheels, as shown by (7) in Fig. 11. The bar is in the mid or neutral position when the handle is at rest. The movement of the regulator to addition and multiplication, or to subtraction and division, decides whether the bar is to move upwards to add, or downwards to subtract.

To illustrate the movements made during division by this machine, suppose that 10 is to be divided by 3. It will be remembered that the handle is turned continually in one direction only. The machine is set to automatic division, *i.e.*, the

counting wheels are to rotate negatively. After three turns are given and 3 is registered, the next turn will indicate 4. This is too great, and the sleeves are pushed forward automatically to positive rotation. Another turn and the 4, obtained in the negative sense, is altered by this addition to 3. The slide moves automatically, and the machine is ready for a new cycle, *i.e.*, for obtaining the next figure of the quotient.

In the Madas the automatic arrangements work very smoothly. There is no trouble as to lifting the slide or plate, either when operating or when setting dividends, or even when effacing the values. The operation of division is so entirely automatic that after setting the divisor and dividend all that remains to be done is to turn the handle till the bell rings, when the quotient and remainder are displayed.

The Monroe Calculating Machine Co., N.Y., has introduced recently a machine which has not only the power of automatic division, but also great adaptability to the rapid evaluation of mathematical formulæ. In its original form it was invented by Mr. F. S. Baldwin (Conn.), whose lifetime since 1870 had been devoted to the design and manufacture of calculating machines.

The present Monroe machine, Fig. 35, suggests in appearance a combination of the Comptometer and the Brunsviga. It possesses a keyboard on a box-shaped frame in front, like a Comptometer, and a sliding carriage at the back, whose working recalls the horizontal cylinder and handle of the Brunsviga.

The adding device is new, and is extremely ingenious. It is a wheel consisting of two parts, like opposed crown-wheels, which can be made to approach each other and to recede. Each crown-wheel consists of a circular disc with five pins round the circumference, perpendicular to the plane of the disc. These pins project into the space between the discs, so that the complete closed wheel suggests the appearance of a very flat squirrel-cage rotor. On the one disc the pins are of equal length; on the other they are stepped in lengths from 1 to 5.

When a numeral less than 5, say 3, is set on the keyboard, the

act of setting makes the discs approach each other in such a way that three teeth of the stepped disc can engage with the counting wheel during one revolution. This is analogous with the operation of the stepped reckoner in a Thomas arithmometer. When a numeral equal to 5 is set, the disc with the 5 equal pins is moved to engage the counting wheel. When a number greater than 5 is set, say 7, the disc with the five equal teeth still engages the counting wheel, but the other disc is pushed up to such a position that its two longest pins also engage, so that on one revolution of the handle the adding wheel turns the counting wheel through seven teeth or units.

The Monroe machine combines the advantages of keyboard setting with the convenient forward (+) and backward (−) rotations of the crank-handle for addition (including multiplication) and subtraction (including division) respectively. Keys and view-holes can be cleared instantly.

For addition the first number is set on the keyboard, and the crank turned forwards. This transfers the number set to the carriage. The second number is then set, and transferred in the same way. The sum is shown in the view-holes. For subtraction the first number is set and transferred to the carriage. The keyboard is instantly cleared and the second number set. The crank is then turned backwards, and the difference appears in the view-holes.

By shifting the carriage totals may be taken at its two ends. If their difference is required, the lesser is transferred by a single turn to the keyboard. The carriage is shifted so that the one number is below the other, the crank is turned back, and the required difference appears in the view-holes.

For multiplication the multiplicand is set on the keyboard. The operation is then carried out as with an ordinary arithmometer, *i.e.*, the crank is turned forward for a number of times corresponding with the last figure of the multiplier. The carriage is then shifted one step to the right, and the operation continued with the second last figure, and so on in succession.

The multiplier appears in the top row of holes; the product in the lower row. A convenient handle in front shifts the carriage one step at a time.

Division is practically automatic. The dividend is transferred from the keys to the lower apertures of the carriage, and the divisor is set on the keys. The operation is carried out in the ordinary way by repeated subtractions. Whenever these have been carried a stage too far a bell rings, which is a signal to turn the crank forwards. The carriage is then shifted one step, and the process continued. A feature of the Monroe machine is the speed with which it can combine the various operations of arithmetic. Thus it is claimed that in about 40 seconds it performs such calculations as—

$$x = \sqrt{\left\{ (283{\cdot}17)^2 - (97{\cdot}63 + 283{\cdot}17 - 154{\cdot}09)^2 \right\}}$$

or

$$x = 53\sqrt{\left\{ \frac{(1{\cdot}5)\ (11{\cdot}5 + 7{\cdot}7/4) + 2{\cdot}25}{15\ (1550 + 54)} \right\}}.$$

Tabulating and Sorting Machines.

Special modifications of engines like the American census machine are used by some large engineering and commercial firms. These are controlled by a Jacquard arrangement, operated by means of punched cards, and may be employed to pick out any group of details for costing. These are larger and more elaborate than the machines already discussed.

In the equipment there are two distinct machines, a set of cards, and a punch. Information, which may be represented generally by numbers, is recorded systematically by forming holes, by means of the punch, in the various columns of items in the cards. A check punch verifies the accuracy of the markings. Each punch has a small keyboard, and is operated somewhat like a typewriter. The cards can be adapted to suit any form of business. The Hollerith and the Powers machines may be selected as typical.

The Hollerith tabulating machine lists and adds from any number of columns. It is worked by a small electric motor. The perforated cards move in succession over a row of copper brushes. When any brush is passed over by a hole in a card this completes an electric circuit to a metal plate beyond the card. This momentary contact is sufficient to actuate an electric relay, which, from the position on the card where the hole representing a number was situated, operates electrically a train of adding wheels, and so adds this item to the previous total. By means of flexible tubes, looking like a small telephone exchange, such items may be grouped in all sorts of ways, according to the requirements of the business, or of the actuary, and added on different recorders. Actually this is very simple to carry out, though it sounds complicated.

Associated with the tabulator is the electric sorting machine. Suppose it be required for purposes of calculation, or of statistics, to select from a vast heap of information, which has been represented by perforated cards, all the details of a certain item. This might be, for example, the time spent on shaping a certain piece which occurred in groups of machines manufactured by some engineering firm. The cards containing all the information about these machines are placed in the electric sorter, and probably in as brief a time as a few seconds it selects every one in which the required item occurs. These may then be transferred to the tabulating machine, and the required total obtained.

As another illustration, suppose that the heap of cards contains unsorted records of a firm's work for a month, each card being dated, and there being any number of cards representing the items for each day. Suppose that these are required to be arranged in order according to the days of the month. On putting these cards into the machine it will deal with them promptly, putting them in order at the rate of 1,500 per hour.

The method of working is similar to that of the tabulator. The punched cards again pass over copper brushes, and the

contact through a hole in the card operates a relay. In this case, however, the function of the relay is to open a pocket, through which the card falls into its appointed place.

The Powers machines accomplish the same results, and in a somewhat similar way, only in this case the fundamental device is mechanical, and no longer the electrical contact through the punched hole in the card.

The Utility of the Calculating Machines.

No one would use calculating machines for every computation. Their special characteristic is that they present a numerical result rapidly, mechanically, and accurately to a long sequence of digits. For successions of arithmetical operations, such as arise in the evaluation of mathematical formulæ, or even in continued multiplications, the resetting of certain factors is necessary with most machines, and this takes time. In order to obviate this trouble some compound machines have been manufactured by certain firms.

In most of the calculations required by an engineer only three or four leading figures are needed, and the rest of the string of digits is unimportant. If merely two or three significant digits are required, the small slide rule is best, or else graphic methods are adopted. For greater accuracy the larger slide rules come in handily, and if still greater accuracy is needed seven or eight figure logarithm tables are what most people use. This tabular work, however, is lengthy, and is very much more tiring mentally than the mere mechanical work of operating a calculating machine. In the case of isolated calculations with formulæ specially adapted for logarithmic methods, and requiring a greater accuracy than can be given by the slide rules, the use of logarithmic tables would no doubt in some cases be the most satisfactory. The superiority of the calculating machine becomes specially marked in such work as the computing of tables, where great speed and accuracy is required, and in the carrying out of large numbers of laborious calculations of a similar type.

Hence from the latter point of view the scope for the use of calculating machines in engineering and commerce is very great.

Now that calculating machines are easily obtainable, there is an increasing tendency among mathematicians to avoid logarithmic calculations, and to use instead the tables of the natural functions with calculating machines. Till recently the mathematician felt that calculating machines were created by a beneficent Providence—in the form of the manufacturer—for his exclusive enjoyment. Now, however, they are widely used by engineering and commercial firms. As there are so many types of machine on the market, the question is sometimes asked —"Which is the best?" To this it may be answered that as each machine is designed for some particular purpose, so it has its own advantages. The prospective user of such an instrument should consider the lines on which his work is likely to lie, and should make his selection accordingly.

The mathematician who may be in the fortunate position of having access to many different machines—as in a mathematical laboratory—would use one for adding, another for multiplying, and a third for automatic division. If he were confined to one instrument alone, he would probably prefer a Monroe, or an arithmometer—particularly one capable of automatic division—or a Brunsviga, as these are easily adaptable to all sorts of operations, though a selected machine might be not necessarily the quickest for any one. The keyboard type would probably not appeal to him in all cases.

On the other hand, for every machine used by a mathematician, a large number are employed in business. For commercial work the keyboard is preferred. The typist who discourses the facile music of the keys can learn with equal ease to extract the harmony of numbers from a keyboard calculator—provided she does not misplace the decimal point; for, after all, in whatever way a calculation be made, the position of the decimal point requires to be checked.

Some of the well-known machines are now fitted with key-

boards, and amongst these is the Millionaire. For work which is chiefly multiplication this latter machine is pre-eminent, and so by the use of tables of reciprocals, division is reduced to multiplication. Those machines which perform division automatically are also in universal favour.

In business work the adding machines are the most widely used. Many recent refinements have been introduced into the large and small Burroughs machines and the Comptometers, and this is specially noticeable in the methods used for adapting the largest Burroughs adding and listing machines to various forms of commercial requirement. These devices range from minimising or preventing mistakes by the false striking of keys to methods of speeding up multiplications on these adding machines, and to arrangements for instantaneously subdividing a machine so as to act as several small ones, whereby not only can many columns be printed and summed at once, but even separate groups of figures in any column can also be summed. These last improvements are particularly useful in book-keeping and accounting. In the large Burroughs machines the paper, and not the keyboard, is moved automatically.

The Elliott-Fisher keyboard machine already referred to, Fig. 25, adds as many columns as may be desired by the device of a keyboard which automatically traverses the paper. At a spot where any column is required a box of adding mechanism is clamped to a bar on the frame of the machine. When the moving keyboard comes to this position it engages by studs the adding box, and prints and adds the item. Not only does this machine add in column, but it also adds in the horizontal lines, so also giving valuable checks and information for book-keeping and accounting.

For general arithmetical work, including the evaluation of mathematical formulæ, the Monroe machine is particularly valuable. Its keyboard and slide arrangement make it very adaptable to many purposes. The large listing and sorting machines are admirable, but at present are rather expensive for universal use.

DESIGN, TREATMENT, AND HANDLING OF THE SNAPS, ETC., USED IN PNEUMATIC HAMMERS.

By G. Denzil Hollis (Associate Member).

23rd December, 1919.

In submitting this paper the author wishes it to be understood that it in no sense professes to affirm that this or that thing is correct and final. It is merely intended to furnish a point of departure, for further investigation and experiment on a subject of great interest to shipbuilders, constructional engineers, and boilermakers, and one in which there appears to be considerable uncertainty as to what are the best designs and treatment of snaps, etc., to avoid incessant breakages, with the concomitant loss of time and money, and the irritation caused to operatives, managers, and all concerned.

The information embodied in the paper has been obtained partly from steel manufacturers who melt the steel, and from it make the various finished snaps, cups, chisel blanks, etc., partly from those making practical use of the tools in different yards and shops, and partly from visits made to carry out suggested treatments at various places where trouble occurred.

Nomenclature.

In the matter of nomenclature considerable divergences exist, for in different yards the tool illustrated by Fig. 1 is variously styled—a snap, a flush-faced riveting snap, a hammer die, and even a hammer. Divergences are less marked in the case of the cup-faced tool, Fig. 2, which is practically always referred to as a cup, or cup snap, though in some cases refer-

ence to it as a snap simply involves the possibility of confusion with a flush-faced snap, also sometimes called a snap.

No confusion at all, however, has been found so far in the terms applied to the various chisels—flat, cross-cut, and caulking—these having always been found to mean the same thing.

Standards.

The collection of the information upon which this paper is based really began with an effort to ascertain if standard

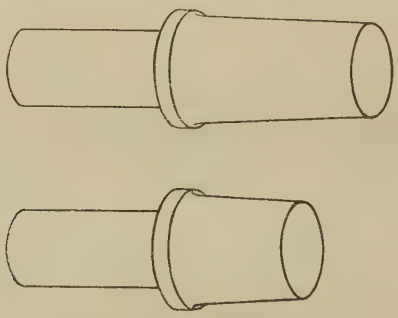


Fig. 1.

dimensions for the heads of these tools (the shanks are, of course, already standardised) could not be established, so that, for instance, a flush-faced snap for 1-inch rivets could only mean one particular style and size of tool. It was early found,

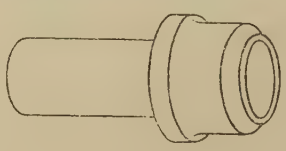


Fig. 2

however, that individual preference greatly affected such points as the length and shape of head, and these preferences were very decided. For example, a flush-faced snap with rather a short head was taken to a certain yard where it was reported on,

after inspection only, as being quite useless, because the shortness of the head made its use impossible without the operator burning his hand or glove on the hot rivet. It was then taken to another yard on the same river, where it was thoroughly tested and pronounced to be a very satisfactory tool of a good and useful type!

Design.

Reference should first be made to the fact that in by far the majority of cases where failure occurs it takes the form of fracture at the fillet, where the shank joins the body of the tool, Fig. 3, and most variations in design are aimed at securing immunity from this trouble. In the usual type of snap, if breakage is to occur at all, this is really the only point where it can take place, as it is the weakest part of the tool, and the

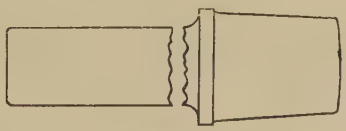


Fig. 3.

one subject to the greatest combination of stresses, as will be explained. Among such variations in design then, there have been met:—

(*a*) The loose-shanked snap, Fig. 4. The author has not been able to discover that this has had any great vogue, and it seems to suffer from the objections of complication in manufacture, possibility of jamming of the loose shank in its socket, owing to the shank end jumping up, and the chance of losing the shank by its falling out of the hammer barrel, in the same way as pistons are not infrequently lost.

(*b*) The snap with a hole bored down its centre from the end of the shank to a point well inside the head, Fig. 5. It was

claimed that this tended to ease any strains which might already exist in the steel. From one establishment where this had been tried a considerable reduction in breakages was reported,

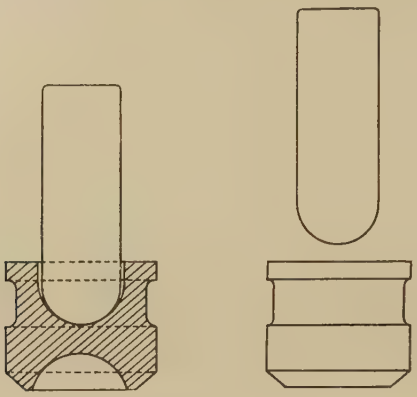


Fig. 4.

while in another case it was stated that no apparent improvement had been observed.

(*c*) The "collarless" snap, Fig. 6. This appears to be a more practical idea, as it practically removes the curve of weakness altogether. In one or two cases where it has been used

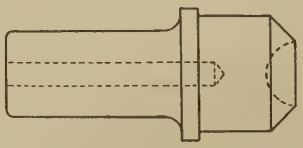


Fig. 5

complete immunity from breakage has been secured. A possible objection to it is the effect it might have on the hammer in that it may tend, on the rebound, to "bell out" the mouth of the barrel. Possibly some hammer makers or other pneumatic experts may be able to give a decision or opinion on this

point, though it may be said that so far no damage of this nature has been reported, and one or two practical men have given their opinion that none should be expected. One firm has used this type for ten months without damage.

Variations in design, as illustrated in Fig. 7, to provide an

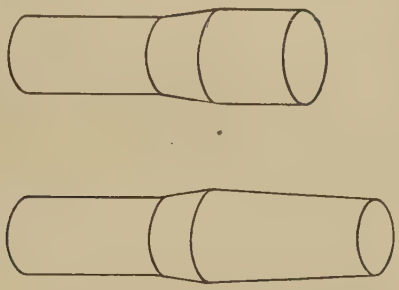


Fig. 6.

improved finger grip for the operator, do not appear to be more than passing fancies.

Differences in the curvature of the face of a flush-faced riveting snap are found within comparatively small limits, for, if the radius becomes too small, the head of the rivet is knocked down with a tendency to concavity, which is viewed with disfavour

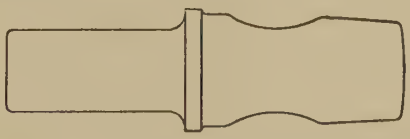


Fig. 7.

by those who pride themselves on the finish of their riveting, and also by surveyors.

In one yard it was asserted that a great reduction in breakages was effected by just removing the sharp edge of the snap face. On the contrary, in another case, the theory was ad-

vanced that, while this sharp edge remained breakages were absent, but as soon as it wore off they commenced, and it was stated that this was borne out by actual experience. It was further claimed that this sharp edge was essential for getting the edge of the rivet head well down on the plate.

Material and Heat Treatment.

Regarding heat treatment of the tools, there are considerable variations of method, though all aim at the same object—namely, to retain hard wearing properties in the face and the end of the shank while obtaining the maximum toughness and elasticity in the middle of the tool, especially at the fillet.

At this point it might be well to consider the stresses to which the tool at the fillet is subject while working, and these seem to be a combination of three, either together or alternating—namely, compression, tension, and bending.

a. Compression takes place between the blow of the piston and the impact on the rivet.

b. Tension occurs when the collar strikes the barrel mouth on the rebound, the action being precisely similar to that employed by a fitter in order to remove a file from its handle (the snap head corresponding to the handle, the shank to the file, and the hammer barrel mouth to the edge of the bench).

c. Bending happens while the operator works the hammer round an imaginary cone, and different edges of the snap bear in turn on the rivet head. This last will be referred to again under the consideration of "Handling."

It thus appears that this work is among the most severe which tool steel is ever called upon to perform, and it is there-

fore considered that a high-grade material is essential if the necessary body and durability is to be found. Various qualities of steel have been tried, from mild steel case-hardened up to high-speed steel, in some cases untreated, in others slightly hardened and then drawn down in temper.

It is understood that with case-hardened material a measure of success has in some cases been achieved, though in others the casing has been found to break down owing to crumbling of the core under repeated shock. At the same time it is thought that case-hardening is more suitable where bearing wear and torsion have to be resisted, than for what may be termed "shock tactics."

At the other end of the scale considerable success has undoubtedly been achieved by some locomotive builders in the use of high-speed steel in the shape of a castellated-faced type of cup snap for use on cold rivets. In one shop the use of this material has secured complete freedom from breakages.

The author's opinion is that a high-grade of pure crucible carbon-steel ought, when correctly treated and hardened, to be capable of giving perfectly satisfactory results without the expense incurred by the use of high-speed steel. Some particulars were obtained of the results of a comparative test of a high-speed steel, a high-grade crucible carbon-steel, and a cheap carbon-steel. The first to fail was the cheap steel, chiefly through fillet breakages, the final decision against this material having been arrived at within a week. In about two weeks the high-speed steel was condemned, mainly owing to shattering of the shanks, which shelled off; while the high-grade crucible carbon-steel continued to give excellent results; in fact, the breakage total for the month of August was one snap.

Coming now to treatment, the most important point seems to be to obtain the greatest possible toughness at the fillet. If the tool is too hard here its brittleness means early breakage, while if it is too soft the steel has not the requisite stiffness to

resist rapid compression and consequent crystallisation and fracture. Thus the mean must be found and the margin is not very great.

A very simple method of treatment, and one which has yielded very good results, is to heat the steel to the usual "bright cherry," about 280° C., just quench the tool nose to a black colour in water, and then cool right out in a mixture of half whale-oil and half tallow. No tempering or further treatment is needed.

Another method, more complicated to carry out, but a very pretty one, and one which gives even better results, is from the same heat, to quench the whole tool in water till the "jarr" felt in the tongs has just vanished, then to cool right out in oil. The tool must then be drawn down in temper, which is done in a large hot nut, or block with a hole in it, into which the snap is placed so that both nose and shank protrude. The tool is kept turning and manipulated so that the colour comes down to a dark blue at the fillet, a rather lighter blue at the end of the shank, and a very dark straw at the nose. The tool is then cooled out and is ready for use.

A third method consists in quenching one end of the tool by holding it in the water and the other by pouring water on it with a dipper, while the middle portion of the tool is in the air, the tool being held vertical during the operation. The temper is drawn back by a special device used in conjunction with the smith's fire. This method is in use in a yard where practically no breakages are reported.

A fourth method in use in a yard where also trouble is completely avoided is a hot-water treatment, of which at the moment full detail is not obtainable.

Enough has been said to indicate that there are undoubtedly several methods of achieving good results, though all aim at the same object above referred to—namely, a fair degree of hardness at the face and the shank end, and toughness at the fillet.

Handling in Use.

The handling of these tools undoubtedly comes within the scope of such a paper as this, as their success cannot be achieved singly by either correct steel, correct treatment, or correct handling in the absence of the other two, but must be sought by a combination of all three. This seems to be borne out by the following two cases. Snaps of the same steel and identical treatment were supplied to a Clyde yard and a Tyne yard. The former were broken at once, while the latter all worked well. Two snaps from the lot sent to the Clyde were transferred to the Tyne and worked well; while two transferred from the Tyne to the Clyde were at once broken. This would seem to establish the fact that handling is a factor. In another case, already touched on as a matter of fact, snaps made from a certain steel were working well in a yard on the Wear. During one month this year a different steel was tried, and forty breakages were reported; a reversion to the first steel resulted in one breakage for a corresponding period. This case suggests that the material is the deciding factor.

It is suggested that an important contributory cause of breakage is the angle of the imaginary cone round which an operator works his hammer in finishing off a rivet. In one establishment close observation was made of two operatives at work, one of whom was known to break as many as three snaps a day, while the other on heavier work seldom broke one at all. It was noted that if the angle of the latter's " cone of working " be represented by the angle ABC, Fig. 8, that of the former was relatively greater, as shown by the angle DBE. It does seem clear that the wider this angle is the greater is the tendency to a bending strain thrown on the shank at the fillet, and it is suggested that the avoidance of breakages will be helped by keeping this angle as small as is compatible with getting the edge of the rivet head down on the plate. It has the added advantage of avoiding damage to the plate itself. This theory is

supported by the evidence of a foreman riveter who, referring to the use of cup snaps, said " he had noted that where the hammer was retained in the axial line of the rivet and the cup relied on to form the head, good work was done and breakages were rare, but that where this ' angling ' of the hammer took place the finish was not so good, and breakages were more frequent."

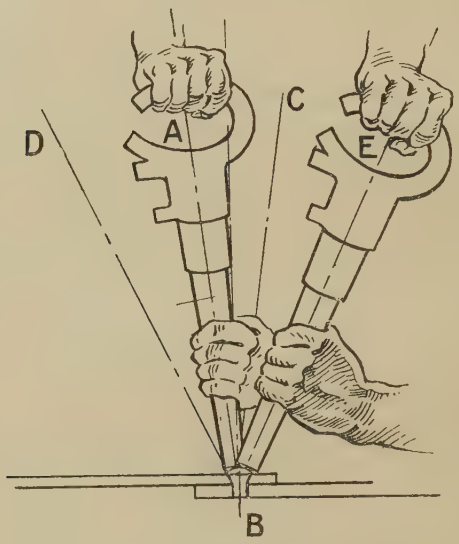


Fig. 8.

Another thing which is held to affect the breakage problem is the amount of play allowed to the snap. If this be great, that is, if the snap is allowed to come far out of the barrel, say half-an-inch or more, it seems evident that the longer travel when the collar returns to the barrel mouth on the rebound permits the development of a blow of considerable force, and thus increases the tendency to break the shank off in the barrel. It is suggested that the harder the hammer is held up against the snap the greater is the likelihood of avoiding breakages.

Weather undoubtedly enters into the question, for it is found that more breakages occur at the start of a cold winter's day than in warmer weather. This, of course, is no more than might be expected, as it is well known that extreme cold produces a tendency to brittleness in the material. It is considered sound practice, in order to combat fatigue in the material, to provide the operator with a pair of snaps, so that, when one gets too hot to handle with comfort, it may be laid aside to cool, and also to rest the steel itself.

Accurate handling of the hammer, to avoid marking the plate and the resultant unsightly finish, is also beneficial to the snap, because the blow is thus delivered by the face of the tool, and not by the outer edge of the face only.

In recording his thanks to the various individuals who have helped him in his investigations with opinions, demonstrations, and in other directions, the author feels that if in the discussion on the paper suggestions are made which will advance this branch of engineering still nearer to perfection its object will have been achieved.

Discussion.

Dr. T. Blackwood Murray (President): While the paper is a short one, it is on a very interesting subject, and one of great practical interest to many members of the Institution, as the use of pneumatic tools is steadily extending. One of the most worrying, and, at the same time, one of the most interesting things in the life of an engineer is the question of dealing with failures of any particular part. Broadly speaking, the engineer has two courses open to him, either to redesign the part, or to decide upon the use of a more suitable material to stand up to the required conditions. In earlier days the engineer had not much choice of material, but to-day he has a very large variety to choose from, materials of which the physical properties are more accurately known. Very often the wiser and the cheaper course in the case of failure is to adopt a different

Dr. T. Blackwood Murray.
material. As an illustration of what I mean, there was in the works of the Albion Motor Car Co. a pneumatic hammer which some years ago gave a considerable amount of trouble. The piston rod continually fractured just above the hammer, or the tup, and the fractures were always coarsely crystalline. Frequently piston rods had to be renewed in the course of about three weeks. At that time great success had been obtained with vanadium steel in the construction of a part which was also subjected to severe shock stresses, and in the case of this pneumatic hammer it occurred to the management to adopt vanadium steel. It was not feasible to make any alteration in design; but with the adoption of a vanadium steel piston-rod previous troubles practically ceased. It appears to me, therefore, that in Mr. Hollis' problem the solution might very possibly be the adoption of vanadium steel, or some of the new alloy steels, which are particularly well suited to stand up to work of this kind.

Mr. R. A. McLaren, O.B.E. (Vice-President): The method of tempering referred to by Mr. Hollis of drawing the tool down in temper by placing it in a heated block with a hole in it, after preliminary cooling, is used by my firm regularly. It has only one disadvantage, that it requires a long time in the block. Still, even with that disadvantage, it is found to pay. Assuming a snap to be properly tempered the principal cause of breakage, so far as my experience goes, arises from insufficient heat in the rivet or insufficient air pressure. With a cold rivet, or a hot rivet closed with a low air pressure, breakage is higher than with the opposite conditions. My firm used to work with a pressure of 80 lbs., which was increased later to 100 lbs. with very good results, and if they were putting down another air-compressing plant they would probably go higher still.

In referring to illustration, Fig. 8, Mr. Hollis spoke of the cone in which the hammer is rotated, or what is commonly called "rolling the hammer." With a properly heated rivet it is unnecessary to roll the hammer; the rivet can be closed

Mr. R. A. McLaren, O.B.E.

almost entirely with the hammer held in the axis of the rivet. It is necessary perhaps to give it one or two rotations just at the very finish, but that is all. If the rivet is not hot or the air pressure is low, the man finds that he cannot get the head formed with the pressure available, and he tries to make up for that by rolling the hammer. Experienced men on piece work, with plenty of air pressure and hot rivets, never roll their hammers. It is a difficult thing to get new men to use the hammer straight, but they gradually abandon the habit of rolling it round, and the result is, as Mr. Hollis says, a reduction in breakages of snaps.

I do not understand why a man should put his hand on the snap at all. That could not be done in the snaps used in the works of my firm as they are short, and only project about three inches out of the hammer. Referring to Fig. 7, snaps made with a reduction in diameter near the top are said to provide an improved finger grip. Here again, I cannot see the need for a man putting his hand on the snap. If the snap is made quite short, obviously that reduced the risk of breakages. I have never seen a snap with a loose head tried, but I think an objection to its use would be the production of eccentric rivet heads, unless the operator got the rivet quite concentric with the first few blows. If it became a little eccentric, the loose head would follow up the rivet, and one would expect to get a considerably eccentric head on the rivet by the time it was closed. With regard to the collarless snap, I would like to ask Mr. Hollis if the barrel of the hammer is bored to the same cone as the snap? If they possess the same conicity, then I do not think there is any reason to fear the damage suggested. The difficulty I anticipate is that it would not be easy to regulate the stroke of the hammer with a cone of that sort. It is generally regulated by the collar itself, and it would be more difficult to turn the cone so as to give a definite stroke.

Mr. David Myles (Member): In view of the great increase in the use of pneumatic riveting, this is a subject of great

Mr. David Myles.

importance. It appears to me that the cause of the breakages is clearly and accurately pointed out by Mr. Hollis, where, in referring to Fig. 8, he says, "the wider this angle is the greater is the tendency to a bending strain thrown on the shank at the fillet," that is the place where the snaps generally break. This will necessarily always occur where the shock of the blow is not correctly on the centre line of the tool—that is to say, if the side of the face of the snap is used instead of the exact centre. This indicates that with any kind of steel it is only a question

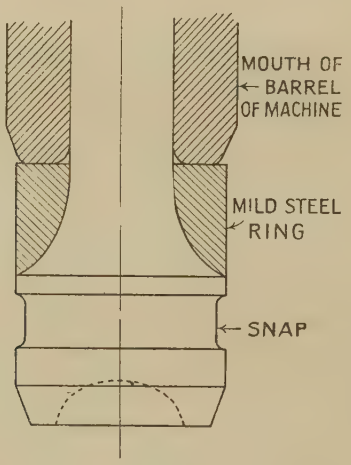


Fig. 9.

of longer or shorter time before the snap will break, and therefore I think the cure is to be found in some method of treatment of the snap after it has been in use, and suggest trying periodic annealing after some time of use to be ascertained by repeated trials. It is possible that this has been already tried, if so, I shall be interested to know the result.

Mr. JOHN F. TAYLOR (Associate Member): Some years ago, during the erection of a large contract for structural work, great difficulty was experienced in getting pneumatic snaps

Mr. John F. Taylor.

for $\frac{3}{4}$-inch and $\frac{7}{8}$-inch rivets to stand the work. They gave way as described on page 165, Fig. 3, after a very short life. Various methods of heat treatment and hardening were tried with little or no success. A modified form of snap was designed, Fig. 9, and its use resulted in breakages becoming practically unknown. These snaps were made long enough to give the stroke for which the machine was designed. The mild steel ring was a slight disadvantage, but on the whole stood up well to the work.

It would appear that the weak point of these snaps is at the neck, and that they would last much longer if the fillet were increased. The makers of the tools might be able to form the mouth of the barrel to take a snap with a larger fillet. Probably a design on the lines suggested by Mr. Hollis of the "collarless" type might be more widely adopted with advantage.

Mr. William Burnside (Member): Until a few years ago I had a fair experience in the use of pneumatic riveters and snaps used with them. From that experience I concluded that the suitability of a snap was almost entirely a matter of material plus heat treatment. When a period of trouble with snaps came round, the practice on work under my control was to get a quantity of snaps made from two or three different makers' steels, and then select that which stood up best to the work. Generally there was not much difficulty in obtaining a fairly suitable steel. Snap after snap might break after a few blows, but when the right material was found the snaps lasted almost indefinitely. When a riveter got hold of a good snap or two he, as often as not, appropriated them, and they were lost to the real owner, but further trouble did not affect the appropriator's squad. As I have indicated, the ordinary design of snap is quite suitable if the steel and its treatment are right. The addition of loose pieces to a pneumatic riveter or snap is objectionable. The snap can be badly used in rolling round the edge of a rivet, and in trying to stave up a cold rivet; this

Mr. William Burnside.
produces bad riveting, as well as being bad for the snap, and should not be allowed.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Associate Member): I should like to compliment Mr. Hollis on his courage in bringing forward a paper on a small matter. It emphasises, however, the importance of small matters, and is quite worth a great deal of acclamation on that account. My personal experience in the use of snaps is exceedingly limited, but I have been inquiring into the practice at Fairfield, and find that a really high-class crucible steel, suitably heat treated, meets the case. The process of hardening at Fairfield is something of this sort. The whole snap is made hot right through, first one end is quenched and then the other. The temper is allowed to draw from the hot metal in the middle, and when the colour is right according to the man's judgment the whole thing is quenched off. As a matter of fact that process, combined possibly with a considerable amount of luck in the choice of the steel, has resulted in an enormous reduction in the breakages of snaps. I visited the graveyard of snaps one day, and it was a very small affair, probably less than that bundle of books (pointing to small pile of books)—an exceedingly good result when there are probably between 100 and 200 hammers out in a day. The experiment suggested by Mr. Hollis of making a snap with a tapered neck has been tried at Fairfield. The snap is not broken, but it also does not do. The reason is just "because"—there is absolutely nothing more to be said about it. It does not fit the man's hand, and he does not like it, because he does not—that is the end of the whole thing; but as a snap it stands quite well and performs good work. Probably when the conservatism of the worker is got over by cajolery, or any other means, that particular form of snap will be perhaps the best of the whole lot. I am informed that, at Fairfield, it is found that better riveting is obtained with snaps of the usual form, but of somewhat larger diameter at the collar—that is, the outside portion that hits up against the

mouth of the hammer is made about a quarter of an inch bigger than the normal size. What the reason for that may be possibly Mr. Hollis may be able to state.

Mr. G. Denzil Hollis (Associate Member): In replying to the discussion on this subject, I would first of all like to thank those gentlemen who have contributed to it, as well for their appreciative remarks as for the very interesting criticisms they have made. My own part in the investigation has been almost entirely that of an amateur, but I have endeavoured to carry it out as thoroughly as possible, and it has led me into a considerable number of yards and into contact with a considerable number of very widely differing opinions. I am extremely sorry, as I am sure everybody in the room is, to hear of the President's indisposition. At the last meeting he made the suggestion that, based on experience he himself had had with a 10-cwt. power hammer, the adoption of vanadium steel might get over the difficulty of the breakage of pneumatic snaps. By a rather curious coincidence, only very shortly before he made those remarks I received for test purpose half-a-dozen snaps made from a mixture specially prescribed, if I may use a medical term, for this purpose, containing this vanadium element, and I am sure Dr. Murray would have been very much interested, had he been here, to hear the interim results obtained from the tests of some of these snaps. They can only be termed interim results because, in my humble opinion, you cannot get definite results concerning pneumatic snaps in less than three or four months. I gave four of these snaps out to test, and they put down numbers of rivets varying from 600 to 3,000, depending on the conditions of the work. They are all reported as doing very well, but two of them are reported as having mushroomed slightly as regards the face and head. This mushrooming made its appearance during the putting down of the first 50 rivets, but after that it did not increase—I may mention that it is a small defect very readily got

Mr. G. Denzil Hollis.
over by a little stiffening in the hardening process without in any way affecting the fillet.

Mr. David Myles suggested that periodic annealing of these snaps might be a cure. That suggestion is, I think, undoubtedly based on sound reasoning, but it involves the continual retreatment of the snap, and, therefore, tends to nullify the good which was originally done to the tool by the forging work that was put upon it. Further than that it involves the complication of keeping track of individual tools and bringing them in at stated periods in their life for this treatment, and therefore it is considered that the difficulty will be better got over by trying to produce a snap that does not require such treatment.

Mr. Taylor suggested increasing the radius of the fillet very considerably, and fitting the hammer with a special collar. I am of opinion that this snap trouble might very likely have been altogether avoided from the outset had the radius of the hammer-barrel mouth been made considerably greater, but I conducted the investigation with the object of trying to confine the cure entirely to the snaps so that they could be used in existing hammers, because there are scores of thousands of these hammers in use, and it would be a tremendous job to alter them, even if the hammer makers approved. Here, again, I think the problem is better solved by means of an unbreakable snap.

I was extremely interested in everything that Mr. McLaren had to say on the subject. He suggested that one of the principal causes of trouble was insufficient heat in the rivet, but I might remind Mr. McLaren that a shipyard worker knocks down the hot rivet that is offered to him, and in quite the majority of cases when he has done that he goes back either to the last rivet or to the one before, and gives it an additional moment or two with the hammer, in which case, of course, he is operating on an absolutely dead cold rivet. Of course, one has to be pre-

pared to produce snaps which will undertake the work of cold riveting from the start. Mr. McLaren also said he had found that low pressure in the air system appeared to lead to snap breakages, which stopped when the pressure was restored to the full 100 lbs. That is very interesting, because at least one hammer maker I know has advanced as an advantage the fact that his hammer will work with a lower pressure than some others that are on the market, even as low as 50 lbs. per square inch. Mr. McLaren likewise agreed as to the harmfulness of rolling the hammer to an excessive angle. In fact, he said that rolling was unnecessary if the rivet was hot enough. In that connection I wish to ask Mr. McLaren whether his remarks applied to cup riveting.

Mr. McLaren: Yes.

Mr. Hollis: I quite agree that with cup riveting there is not the slightest need to roll the hammer at all.

Mr. McLaren: But they do it.

Mr. Hollis: That is true. In riveting with a flush-faced snap a certain amount of rolling is essential, because it does not appear that one can otherwise knock down a rivet with a convex head except by rolling the hammer. Mr. McLaren could not understand why a man should put his hand on the snap at all in cup riveting. I quite agree with that. There is no need for a man to put his hand on the snap because, a cup being self-centering, it is only necessary to support the hammer and apply the necessary pressure. With regard to riveting with the flush snap, of course the snap has to be guided and held to its job, and obviously the nearer one can get to the rivet the easier and more complete is the control of the hammer, and, while in some yards I have come across the men do not hold the snap, in the majority of cases they do. In some instances when riveting underneath a ship the hand is held with the thumb and forefinger upwards, and in others with the little finger upwards, but in every case holding the snap. Mr. McLaren recommended

Mr. G. Denzil Hollis.
short snaps as not being so liable to break. There again I think the argument is perfectly sound, because the longer the snap the greater is the leverage. One official said he considered that a long head gave a better blow than a short head. I could not follow this, unless he had based it on an inertia argument. Commenting on the loose-headed snap, Mr. McLaren said it might produce an eccentric-headed rivet. For the reasons stated in the paper I do not think the loose-headed snap is a practical proposition at all. With regard to the snap without a collar, but simply with a taper, Mr. McLaren thought there is no reason to fear damage if the barrel of the hammer is bored to the same cone as the snap. Well, that view is very interesting, because my experience of the use of collarless snaps has been entirely with the hammer unaltered, and in one case, covering a period of twelve months' use, no damage to the hammer barrel resulted. The officials in one yard did report a little air leakage between the barrel of the hammer and the shank, but they said that was principally in the case of old and very worn hammers. I think the collarless snap perhaps deserves a little more attention. It generally meets with opposition to begin with, exactly as Mr. Riddlesworth said. It is a new idea, and in this funny country of ours a new idea always meets with opposition—I do not know why. But it has certain apparent disadvantages. It does stick in the hammer mouth slightly. Another objection advanced is that there is no collar for the spring clip. Well, the use of the spring clip is to retain the snap in the hammer barrel, and if by reason of its conical shape it sticks in the hammer barrel there is no need for a spring clip. Theoretically, if it sticks the force of the blow will be decreased, because some of the air power is used in freeing it from the barrel, but in practice there does not appear to be any reduction at all in the speed with which a rivet can be knocked down. Then against these objections there is a very important point, that it is a very much cheaper snap

Mr. G. Denzil Hollis

to make. There is less work on it and less steel in it, and the cost is, roughly, about 60 per cent. of the snap of the ordinary pattern. It is also lighter, and some hammer makers and some users claim that it is advantageous to keep the driven weight as low as possible. And, lastly, it certainly does seem to remove the point of weakness, the fillet. Two yards refused it—one because the men jammed their fingers, and the other simply because the men did not like it, exactly as Mr. Riddlesworth said. One very interesting case occurred in which a snap was condemned on inspection only. I was trying to get an unused snap tested, and the opinion of an expert riveter was asked. He examined the snap most critically, put his rule on it, asked everything about it, and finally said: "Of course, it cannot be used at all." I said, "Why not?" "Oh," he said, "it would not work in the hammer." I said, "Why?" After he had given several reasons I produced from my pocket this snap (exhibiting snap), and said, "How do you account for the fact that this has already knocked down 11,000 rivets?" His face was a study. Perhaps it was not very fair, but I knew him well enough to take advantage of the opportunity for a little banter when it presented itself.

Mr. Burnside is of opinion that the solution is to be found in high-grade material and correct heat treatment, and, with certain reservations with regard to handling of the tools in use, I think he is perfectly right. He referred to good snaps being appropriated. Now, in the case of the particular tool which the Vice-President has now in his hand I got it tried in a yard, and some considerable time later 'phoned asking if I might have it back, with a report as to how many rivets it had knocked down. The reply came back: "Yes, come down this afternoon." I went, but the tool could not be found. Four days later it was got from a man who had stolen it from the man who had purloined it from the original man who had got it! It was burnished; he had carried it about

Mr. G. Denzil Hollis.

with him, and I believe he had actually taken it home with him! Several other men had asked for the same pattern from the store.

Mr. Riddlesworth's remarks, I think, I have already covered, excepting the final point he made, that better riveting is obtained with the usual type of snap with a somewhat greater diameter of collar. That is interesting, because in one yard a snap with a large diameter of collar, I think it was about $2\frac{1}{8}$ inches as against $1\frac{7}{8}$ inch, had been looked upon as a standard type, but eventually it had to be given up. The users simply said it did not do. A great many people do not realise that they are having difficulties. A number of users seem to take it quite as a matter of course for a snap to break after it has knocked down 500 rivets. Now, 500 rivets is absurd. An official in one firm who make their own snaps, which are heat-treated very much in the way Mr. Riddlesworth described, showed me a tool the other day which was in a very good condition, and yet it had put down 18,000 rivets. Another firm had snaps supplied in May of last year treated by one of the methods mentioned in the paper, the method of quenching the face in water, and then the whole tool in oil, and not one had been broken yet. This particular firm must possess snaps which have put down from forty to sixty thousand rivets. Such results should be obtained, and I think firms who find that they can only get from 500 to 2,000 rivets knocked down before the snap breaks ought to investigate the matter to avoid unnecessary waste.

THE DEVELOPMENT OF METAL CONSTRUCTION IN AIRCRAFT.

By Major J. S. Nicholson, O.B.E., R.A.F.

20th January, 1920.

In the past, with the exception of the engine, the material of construction for the structure of the aeroplane has been timber.

During the war, when particular types of machine were required by the thousand, with spare parts in proportion, one of the chief essentials in the design was simplicity and ease of construction. The life of a machine was counted in weeks or even days, and consequently durability was of less consequence than cheapness and rapidity of construction. Further, as long as the number of machines under construction was small, it was possible to obtain and select good qualities of timber, light, straight in the grain, and strong. Timber, therefore, was the natural material to adopt for the construction of the entire structure of the aeroplane.

On the other hand, timber is a most unsatisfactory material, from the point of view of durability. It cracks and warps easily, and is affected to an extraordinary extent by the weather. Tests on timber show that the strength diminishes rapidly as the percentage of moisture increases. Good dry spruce may have a strength in compression of six tons per square inch, whilst with 30 per cent. of moisture the strength will fall to about two tons per square inch. The weight of the different samples of the same species of timber also varies within wide limits.

An aeroplane built of timber is, therefore, unreliable; it deteriorates very quickly, and requires frequent trueing up. It withstands "landing" shocks badly, and in an accident vital members splinter badly, possibly causing a complete crash.

On the other hand, metal construction is reliable. The material is uniform, its strength can be definitely determined, and, apart from corrosion, it is unaffected by atmospheric conditions or by lapse of time. It is unnecessary to say more about the relatively good qualities of metal.

Further, now that the war is over and the commercial aeroplane has to be developed, it is essential that the machine be, above all, reliable; it must have a reasonably long life; it should require the minimum of overhauling and trueing up, and, consequently, ease of construction need not be such an important factor as it was during the war.

For all these requisites metal is superior to timber, and in the event of an accident through, say, a bad landing, one may safely count on the localising of the damage to the part which took the blow, and on the damaged part merely crumpling and not splintering.

METAL CONSTRUCTION.

Experiments have amply proved that it is possible to build aeroplanes with metal structures to the designs adopted for the wooden machines, and that the metal machine may also be lighter and stronger than the wooden machine.

The ordinary materials of construction for the vital members of the structure of the all-metal machine are steel and duralumin, and before proceeding further it will be advisable to compare the physical constants of these materials with grade A spruce.

The specific gravity of dry spruce is 0·45 grams per cubic cm.

,, ,, ,, steel 7·8 ,, ,,

,, ,, ,, duralumin 2·8 ,, ,,

The strength of spruce under combined bending and end thrust should be taken as 5,500 lbs. per square inch.

From compression tests on angles, channels, tubes, etc., the crushing strength of duralumin may be taken as from 18 to 20 tons per square inch, but from tests on built-up girders under combined bending and end thrust a maximum stress of 24 tons to the square inch has been developed in the compression boom. The tensile strength of properly heat-treated duralumin is 26 tons per square inch.

Young's modulus, E, of grade A spruce should be taken as $1{\cdot}6 \times 10^6$ lbs. per square inch, or 714 tons per square inch. E for steel varies from 12,500 tons to 13,500 tons per square inch, and E for duralumin is 4,800 tons per square inch.

The present paper will be limited mainly to the structural design of the main-planes, and to the developments which have recently taken place in the construction of the all-metal aeroplane.

The structural design of the main planes and fuselage largely resolves itself into the design of struts and beams and of struts with lateral loading. A brief résumé of the scientific principles underlying their design may, therefore, not be out of place.

In simple bending with the usual notation, we have

$$\frac{M}{I} = \frac{f}{y} = \frac{E}{R} \quad - \quad - \quad - \quad - \quad (1)$$

$$\text{or } M = \frac{fI}{y} = f \times Z \quad - \quad - \quad - \quad (1a)$$

$$\text{and } M = \frac{EI}{R} \quad - \quad - \quad - \quad - \quad - \quad (1b)$$

In long struts with ball end loading, the Euler crippling load $Q = \frac{\pi^2 EI}{l^2}$ applies.

In beams, therefore, for a definite curvature $\frac{1}{R}$ the applied bending-moment M is proportional to the product EI, and in

long struts the limiting end thrust Q is also proportional to the product EI.

Young's modulus E should, therefore, be as great as possible, and any improvement in the value of E will enable a corresponding increase in load to be carried. Young's modulus E of the material may frequently be improved by a suitable heat treatment, or what is of equal importance, the elastic limit and the yield stress of the material may be considerably increased by heat treatment.

The moment of inertia I of the cross-section of the beam or strut is also of prime importance, but, as we shall see that the members of the aeroplane structure usually fail under compression and not in tension, there is usually a definite limit to the increase in the value of I for a definite design with a limiting weight of the structure. The moment of inertia I is limited by questions of stability of the structure.

Stress Developed in a Portion of the Structure at Failure.

In general we have not to deal with cases of simple beams or struts, but of combined bending with end load where the failure occurs by buckling under the combined compressive stresses due to the direct end thrust, together with the stress due to the transverse bending-moment and to the end thrust bending-moment when the beam or struts deflect laterally.

Consider a strut or spar with a lateral bending-moment distributed as shown in Fig. 1, and with an end thrust P applied through pin joints.

Pin-Jointed Strut with Lateral Bending-Moment.

Let the deflection at the centre be δ and M be the applied bending-moment due to the lateral loading on the strut, then with the usual notation the compressive stress

$$f_c = \frac{P}{A} + M\frac{y}{I} + P\delta\frac{y}{I} \quad - \quad - \quad - \quad (2)$$

In general the stress $P\delta \times \frac{y}{I}$ is not small in comparison with the other two terms, and must on no account be neglected. In the main-plane spars it increases very rapidly with the loading; in certain cases it varies as the square or even the cube of the loading, and soon becomes of the first importance.

It is assumed that the failure of a member of the structure, or of a portion of the member, is determined by the compressive stress which is developed in that member or in the part of the member or, in other words, that in a given design a particular

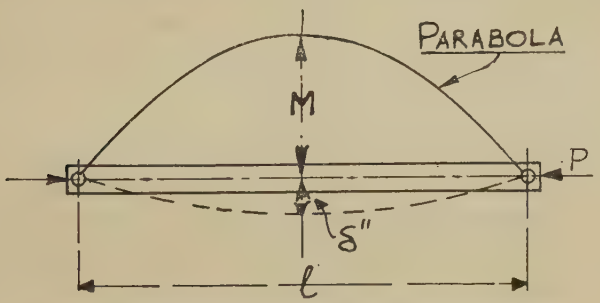


Fig. 1.—Pin-Jointed Strut with Lateral Bending-Moment.

member will just fail when the compressive stress in that member reaches a definite value dependent on the design.

A knowledge of the total stress f_o in equation (2), which can be developed at failure in any given design, should therefore be acquired.

Assuming a uniformly distributed lateral loading of w lbs. per foot run on the strut or spar in Fig. 1 giving a parabolic curve for the bending-moment diagram, and adopting the Perry formula for the bending-moment M_o which is equivalent to the total bending-moment $M + P\delta$,

$$\text{then } M + P\delta = M_o$$

$$\text{and } M_o = \frac{M}{\left(1 - \frac{P}{Q}\right)} = M\left(\frac{Q}{Q - P}\right).$$

Q is the Euler crippling load $\frac{\pi^2 EI}{l^2}$ for the strut and P is the applied end thrust passing through the centroid of the cross-section of the end of the strut.

Then equation 2 becomes

$$f_c = \frac{P}{A} + \left(\frac{Q}{Q-P}\right) M\frac{y}{I} \quad - \quad - \quad - \quad (2a)$$

Secondary Flexure.

It has been stated above, that for a given design of spar any increase in I beyond a definite value will affect the stability of the structure, and will probably result in an unstable design liable to secondary failures.

In aircraft construction, where lightness of structure is of great importance, such secondary failures of a portion of the main structure, due to the crumpling of a small member of the structure, may easily occur unless all the individual members have been carefully designed, and such secondary failures at low fibre stresses have in most cases been the cause of failure of the experimental spar and strut designs put forward for test.

To fix our ideas on secondary flexure, let us consider briefly the aeroplane main-plane-spar designs illustrated in Figs. 2a, 2b, 3, and 4a, 4b, 4c. The first three represent a steel-girder type construction, and the latter three a modified type with continuous booms, all being approximately 4 inches wide by 8 inches deep.

Figs. 2a and 2b show short lengths which were tested to destruction as struts with ball end loading, whilst Fig. 3 shows a portion of a longer specimen which was loaded laterally with concentrated loads at the two tubular boxes shown, together with an end thrust applied through pins with axes parallel to the boxes, and passing through the centroids of the cross-section.

The proof loading was an end thrust of 80,000 lbs., together with a transverse load of about 1,000 lbs. at each of the two loading boxes,

Failure of the girders may occur in one of the following ways:—

a. By bowing as a whole sideways about the $y\ y$ axis.
b. By bowing as a whole downwards about the $x\ x$ axis.
c. By bowing of the compression boom sideways.
d. By bowing of one corner angle member on a free length equal to the pitch of the web bracing.
e. By buckling of one of the flat faces (free lips) of an angle.
f. By failure of a web member.

In these specimens the end thrust was so great that any local secondary failure instantly resulted in the collapse of the whole specimen. This collapse was so sudden that it was frequently difficult to decide whether the secondary failure preceded or followed after the complete failure.

The failing stress in the various members was determined largely by the ratio (a) $\frac{L}{K_{yy}}$ of the whole spar; (b) $\frac{L}{K_{xx}}$ of the whole spar; (c) $\frac{L}{K_{yy}}$ of the compression boom; (d) $\frac{l}{k_{min.}}$ of a free length of the corner angle; (e) $\frac{s}{t}$ or side of angle to thickness of side; and (f) $\frac{l}{k_{min}}$ of a compression member in the web.

In failure (c) the ratio $\frac{L}{K_{yy}}$ is the same as that for lateral bowing of the whole spar, but in the specimen in Fig. 3 one of the booms has its crushing stress reduced by the lateral loading, and, consequently, there is a tendency for one boom (the so-called compression boom) only to fail.

The specimens in Figs. 2a and 3 have failed by the lateral bowing of one boom, caused partly by the weakness of the bracing on the boom, which allowed the two angles to act to a certain extent independently of each other. Under the end thrust the top bracing slackened sufficiently to allow one angle to bow sideways, and then to pull the other angle with it.

A specimen of the design shown in Fig. 2a, but tested as the specimen in Fig. 3, also failed by bowing of the compression boom at a stress of 34 tons per square inch in the angles. Bowing took place mainly in a length of 22 inches between the lateral loading boxes; the ratio $\frac{L}{K_{yy}}$ was therefore approximately $\frac{22}{2}=11$, and failure should not have occurred at a stress less than 50 tons per square inch, the yield stress of the angles.

The specimen in Fig. 3 failed in a similar manner, but with a stress of 58 tons per square inch in the angles.

In failure (e) Fig. 2a shows that, in addition to the bowing of one boom as a whole, the lips of one angle have developed secondary failures. Good examples of similar failures of type (e) are also given in Fig. 2b, where the specimen with ball end loading developed a stress of 55 tons per square inch in the angles at failure.

A good example of type (f) failure of the web elements is given in Fig. 4c, where the compression elements failed under a stress compounded of the direct compressive stress plus the bending-moment stress due to eccentric loading of the elements. The compression elements buckled, and finally the tension elements tore away the rivets.

A very interesting failure of type (d) is shown in Fig. 4b, where the whole compression boom buckled on a short length equal to the pitch of the web bracing. The failure, however, is peculiar, and is possibly due to the very stiff adjacent loading box for the lateral loads. The $\frac{l}{k}$ for this panel was about 30, which for free-ended angle struts should correspond to a stress of about 45 tons per square inch.

In the specimen in Fig. 4c the stress developed at failure was, however, only 43 tons per square inch.

The question of secondary failures should therefore be carefully studied. The structure as a whole, and also each portion, should be rigid enough to hold the various members up to their

proper functions and prevent early and excessive deflection or bowing of any member or portion of a member, thus producing the perfect design where the structure fails as a whole, because each part fails on developing the ultimate stress possible in the material of which the structure is built.

Designs should therefore be compared from the point of view of the maximum stress which can safely be developed in the structure, of given overall dimensions and weight, as well as the total load which the structure will carry before failure. The test structure should be constructed of material having a yield stress considerably higher than would be developed or is expected to be developed in the structure.

Careful records should then be taken of the deflections of the structure, under gradually increasing loading, and the stresses calculated and plotted against load factors, the load factor being the ratio of the load under test to the unit load corresponding to normal conditions of flight. The most stable designs can thus be separated from the others, and a distinction made between them and the remaining designs which are good enough for the immediate purpose in view, but which may be incapable of application to structures of slightly increased dimensions.

Steel Versus Duralumin Designs.

Since rigidity enters so largely into the problem of designing a structure of minimum weight, it is obvious that a design which is good enough and safe enough in duralumin may be impossible in steel.

In duralumin Young's modulus is 0·37 Young's modulus for steel, and for the same type of design with the same weights and overall dimensions,

$$\text{I for duralumin} = \frac{7{\cdot}8\text{I}}{2{\cdot}8} = 2{\cdot}78 \times \text{I for steel},$$

$$\text{hence EI for duralumin} = 0{\cdot}37 \times 2{\cdot}78 \text{ EI for steel},$$

$$= 1{\cdot}03 \text{ EI for steel}.$$

The duralumin and steel beams or struts should, therefore, be equally strong. The duralumin specimen, however, will have greater rigidity against secondary failures than the steel specimen, since, for equal weight, its individual members will have 2·78 times the thickness of the corresponding members in the steel specimen, and, consequently, the duralumin specimen should be the more stable of the two. Also, by a final readjustment of the material throughout the cross-section, say from the webs to the booms, it should be possible to obtain better results by the use of properly heat-treated duralumin than from steel.

For equal rigidity the design in duralumin will be simpler and easier to produce than the design in steel; and, further, this design in duralumin will probably, for equal weight, have a relatively better moment of inertia I than the steel specimen, and, consequently, the deflection of the structure and the corresponding stresses due to end thrusts will be less, giving considerably improved load factors. This feature will be more fully illustrated in connection with the strength of the main spars in aeroplane wings.

At the present moment, whilst a number of excellent designs of steel main-plane spars are available for the smaller types of aeroplanes, equally suitable designs in steel for the main-plane spars of the larger types of bombing machines, such as the Handley-Page V 1500, have not been produced. Designs in duralumin have, however, already been so promising that I understand Messrs. Vickers & Co. Ltd., Barrow-in-Furness, are proceeding with the design in duralumin of these members for the latest and largest type of flying-boat.

One of the chief reasons for the delay in the past in the development of designs in steel for the larger machines was the difficulty in obtaining supplies of materials of requisite dimensions in the forms which experience had proved satisfactory for the designs of main-plane spars and ribs for the smaller-sized machines.

The principal material was high-tensile steel strip, and this was difficult to obtain in widths greater than 5 inches with thickness from ·018 inch upwards.

CHOICE OF TYPE OF AEROPLANE FOR PURPOSES OF EXPERIMENT.

Attention was first of all concentrated on the Avro 504 K aeroplane, because it was the standard training machine not subject to any serious modifications, and because it was required in such large numbers that success in the experiments would mean an appreciable decrease in the consumption of timber for aircraft purposes, and would also furnish the necessary bulk experience in the manufacture of all-metal planes and machines.

It should also be emphasised that one essential proviso laid down for the all-metal design was interchangeability with the standard wooden plane, and hence the design of the all-metal wings has been very similar to that of the standard construction in wood. Rightly or wrongly, therefore, the design of the metal main planes has followed the two-spar construction with frequent ribs of aerofoil section, adopted in the manufacture of wooden planes.

The approximate stress and bending-moment diagrams for the wing-truss system of this machine, for the cases of normal flight with the centre of pressure forward and centre of pressure back, are given in Figs. 5 and 6.

For the upper plane the unit loads on the front spar in the inner bay were taken as 850 lbs. thrust with a transverse bending-moment of 480 inch-lbs., and for the rear spar in the inner bay the unit loads were taken as 1,700 lbs. thrust, with a transverse bending-moment of 480 inch-lbs., corresponding to a uniformly distributed loading on the spars of 1·73 lbs. per inch run.

For purposes of experiment the main-plane spar test specimens were finally chosen of length PQ, Fig. 6, equal to the distance between the points of inflection in the inner bay of

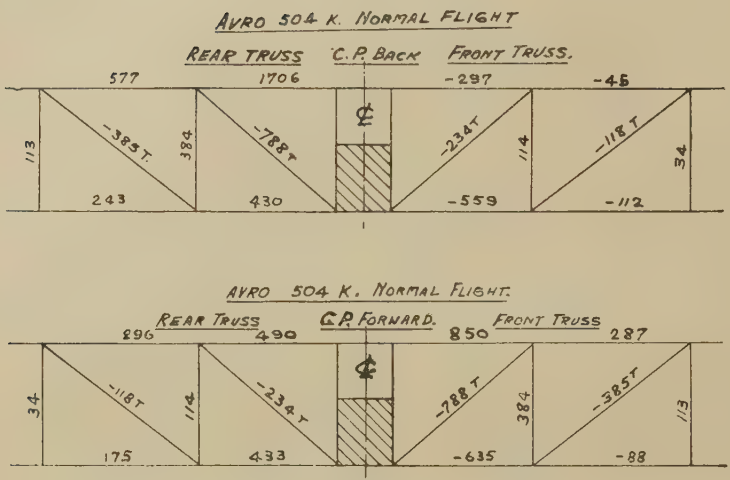


Fig. 5.—Stress Diagrams, Avro Machine.

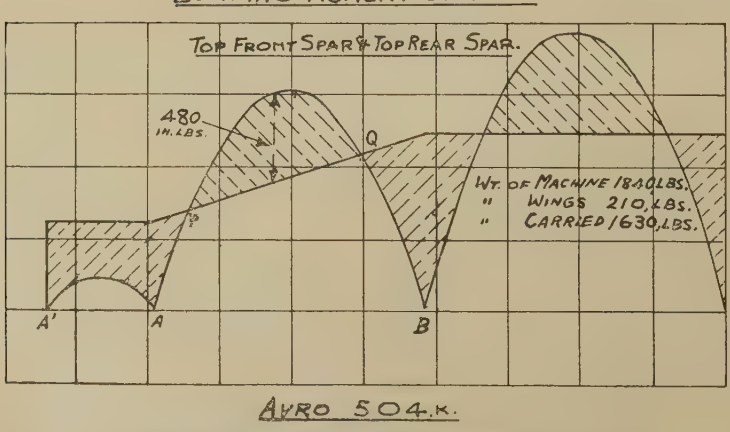


Fig. 6.—Bending-Moment Diagram for Avro Main-Plane Spars.

the wings. This distance in the Avro was taken at a constant value of 50 inches. In the standard wooden wings the front spar is $2\frac{1}{2}$ inches deep, and the rear spar 2 inches deep; their average weights for dry, grade A spruce were 0·58 lbs. per foot and 0·63 lbs. per foot respectively.

A very large number of designs and test specimens for these Avro front and rear spars were prepared, and analysis of the test results shows that for machines of this size a steel or a duralumin spar of weight equal to that of the wooden spar may have a strength of 50 per cent. in excess of that specified. It was found that the better examples of these designs were all modifications of the box type of girder with booms and webs of continuous strip, corrugated to differing forms to obtain the necessary rigidity. The web strip is frequently lightened to a lattice type of construction.

Duralumin Spar Specimens.

Views of two types of duralumin spars, produced by Messrs. Vickers & Co. for the Avro machine, are given in Figs. 7 and 8. These specimens all developed from 16·5 to 18 tons per square inch in the material of the compression boom at failure under the loading specified for the Avro spar specimens.

The front spar specimen to the design in Fig. 7. is 10 per cent. lighter than the standard wooden spar, and develops a load factor of 7·2 against the specified 6; whilst the rear spar specimen is 5 per cent. lighter than the corresponding wooden spar, and develops a load factor of 4·72 against the specified 4. An earlier test specimen, however, designed by Prof. F. C. Lea, and in which the booms were convex outwards instead of concave as shown in Fig. 7, developed the remarkable stress of 23·7 tons per square inch in the compression boom at failure. This specimen was 28 per cent. lighter than the standard wooden spar, and withstood a load factor of 5·86 against the specified 6. The convex-shaped boom plates were recognised to be the better design, but owing to the difficulty in attaching the stand-

ard wing fittings to this form of boom, Messrs. Vickers decided to adopt the concave form.

In these designs the weak feature is the riveted flat lips forming the junction between the webs and the booms. The lips fail, as shown in Fig. 7, at a compressive stress of about 18 tons per square inch. The method of stiffening the webs by pressing out the free lips of the horizontal and vertical members is shown. The pitch of the web panels is equal to the depth of the spar.

This design compares most favourably with all the steel specimens, and from its behaviour in tests on the complete wing structures and in flight one may confidently predict excellent results with all-metal planes of this type of construction.

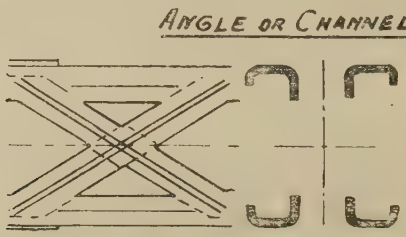


Fig. 8.—Channel Type of Small Spar in Duralumin.

The channel type front-spar specimen, shown in Fig. 8, was 16 per cent. lighter than the standard Avro wooden front spar, and withstood a load factor of 6·72 at failure, against the specified 6. The stress developed was 17·8 tons per square inch. Failure commenced by buckling of the free lips of the channels on the compression boom. On cutting away these lips and retesting, the load factor in the lightened spar fell to 4·9, but the stress developed at failure increased to 19 tons per square inch. This particular specimen is of importance chiefly for the purposes of comparison with the similar types of construction in steel illustrated later. These steel specimens were all rather heavy, and usually developed at failure stresses which,

for steel, do not compare favourably with the 18 to 19 tons per square inch in the duralumin specimen.

Steel Spar Specimens.

A view of the Rudge type of main-plane spar, designed by Major H. N. Wylie, and manufactured by Messrs. Rudge-Whitworth & Co., is given in Fig. 9. This type of spar may be regarded as a modification of the box girder type, with the webs drawn together and riveted, forming a waist at the neutral axis. The webs thus mutually support each other and the free edges of the booms. The design may also be regarded as consisting of two tubes mounted one above the other, and fixed together at

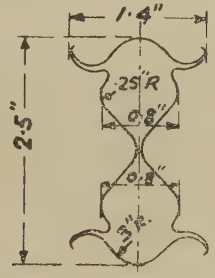


Fig. 9.—View of Section of Rudge Spars.

the waist by riveting. Since the loading on these spars is compounded of a lateral bending-moment with a relatively large end load, the close approach to the tubular construction for the compression boom of the spar makes for great rigidity.

This type of design has given excellent results. An Avro front-spar specimen, 8 per cent. lighter than the standard wooden spar, gives a load factor of 8 at failure, against the specified 6, and develops a maximum fibre-stress of 64·6 tons per square inch at failure, which occurs by a crumpling of the riveted edge of the compression boom. Note should be taken of the sharp curvature in the web where it meets and supports the free edges of the corrugated boom strips. The free edges of the

boom are situated about 80 per cent. of the maximum distance from the neutral axis, and hence the maximum stress which can be developed is about $\frac{100}{80}$ or 1·25 times the stress which the stiffened free edges will withstand.

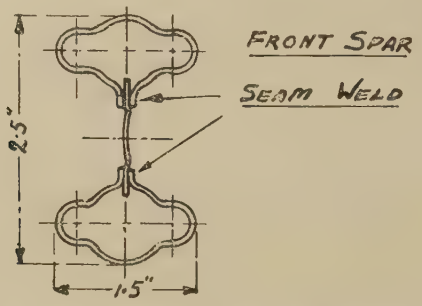


Fig. 10.—Section of Dunlop Avro Steel Spar with Short Web.

The designs shown in Figs. 10 and 11, due to Major H. N. Wylie, and manufactured by Messrs. The Dunlop Rubber Co., get over the inherent weakness of free lips at the edges of

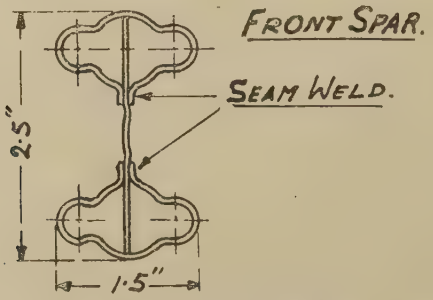


Fig. 11.—Section of Dunlop Avro Spar with Long Web.

the booms in a very ingenious manner, and transfer the riveted or welded joint closer to the neutral axis. The booms of this spar are rolled and bent over to shape in one continuous opera-

Fig. 2a.—Main Plane Spar Design, approximately 4 inches by 8 inches, showing Steel Girder Construction.

Fig. 2b.

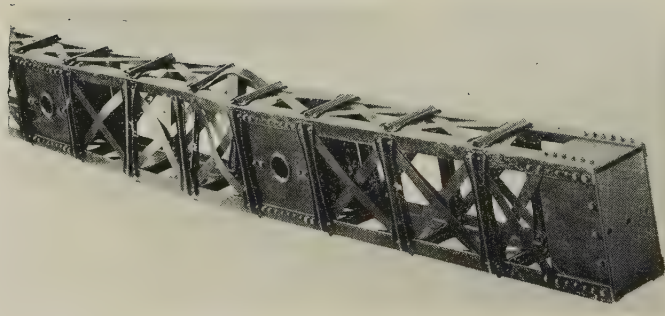


Fig. 3.

Figs. 2b and 3.—Main Plane Spar Designs, approximately 4 inches by 8 inches, showing Steel Girder Construction.

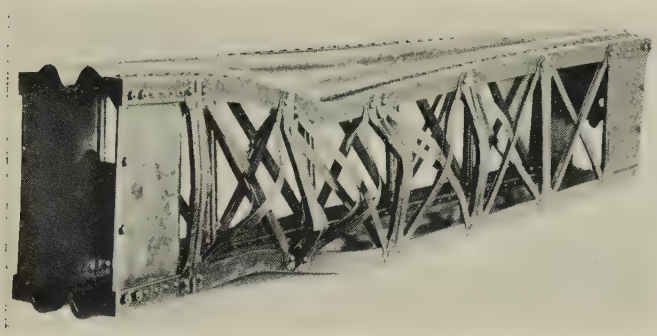


Fig 4a.

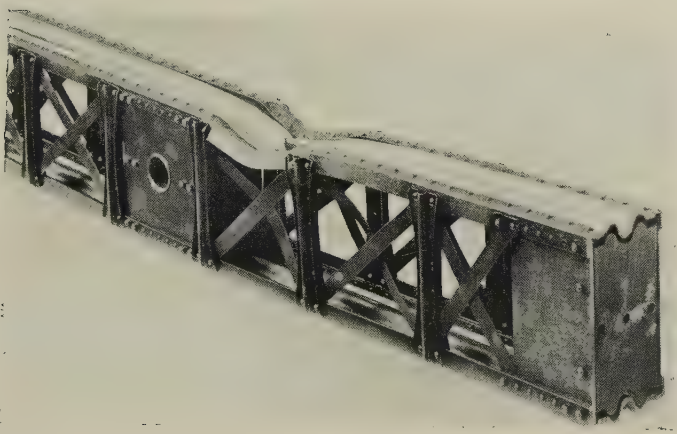


Fig. 4b.

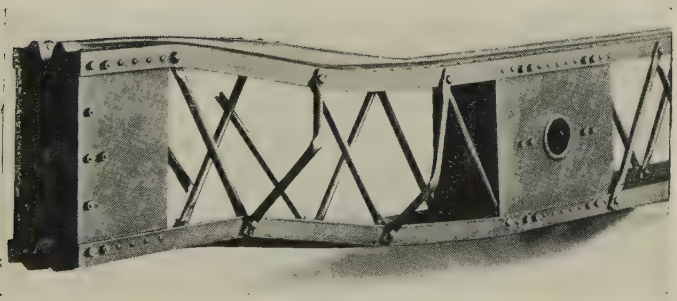


Fig. 4c.

Figs. 4a, 4b, and 4c.—Main Plane Spar Designs, showing Steel Construction with Continuous Booms.

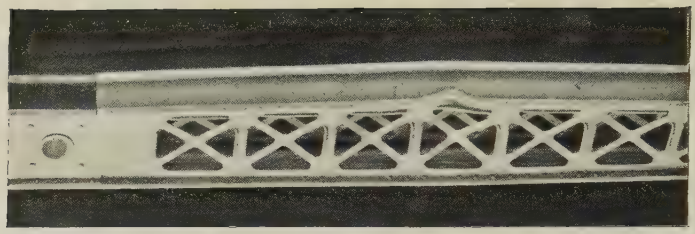


Fig. 7.—Avro Spars in Duralumin.

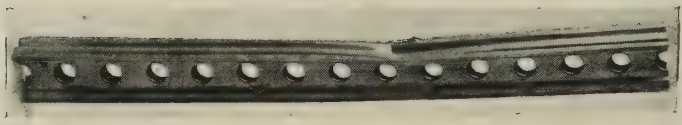


Fig. 13.—Boulton and Paul Avro Steel Spar Specimen.

Fig. 16.—Avro Steel Spar Specimen by Messrs. The Steel Wing Co.

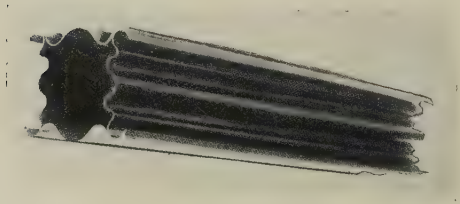


Fig. 18.—Later Avro Steel Spar Specimen
by Messrs. The Steel Wing Co.

tion, and are finally strip-welded to the continuous web before leaving the set of rolls.

Electric welding, however, has so far not been satisfactory in the case of alloy steel strip, owing to the formation of minute cracks round the weld when cooling occurs. Satisfactory welds have, however, been obtained with straight-carbon steel strip, and owing to this difficulty the web plate should preferably be attached to the booms by riveting. This spar design may be assumed to be a development of the Rudge spar, or else to be a special form of I girder. It is very rigid against torsion.

An Avro front spar specimen built of soft steel to facilitate welding with short web equal in weight to the standard wooden spar withstood a load factor of 7·5 at failure, by buckling of the compression boom, against the 6 specified, and developed a maximum fibre stress of 54·8 tons per square inch in the compression boom; the modified section with the web extended to the crown of the booms, and weighing, in consequence, 7 per cent. more than the standard wooden spar, withstood a load factor of 8·1 at failure on buckling of the compression boom, and developed a maximum fibre stress of 58·8 tons per square inch on the compression boom. In both cases the booms were ·019 inch thick, and the webs approximately ·018 inch thick. The influence of heat-treatment on the Dunlop specimen is clearly shown by the curves T_1 and T_2 in Fig. 25.

The design illustrated by Fig. 12 is due to Prof. Lea, and the booms were supplied by Messrs. The Dunlop Rubber Co. It consists of an ordinary cycle-rim boom section, together with webs of the Rudge pattern. This form has a number of valuable features; it practically eliminates the weakness of free lips at the edges of the booms, and gives a very robust spar capable of withstanding a lot of rough handling, or even blows, which could be taken by the beaded edges of the booms. This sample was built up from standard cycle pieces, and could be considerably improved by making the booms convex upwards, and by slipping the free edges of the webs inside the beaded edges.

A specimen weighing 6 per cent. more than the Avro front wooden spar withstood a load factor of 9·3, against the 6 specified, and developed a maximum fibre stress of 78·5 tons per

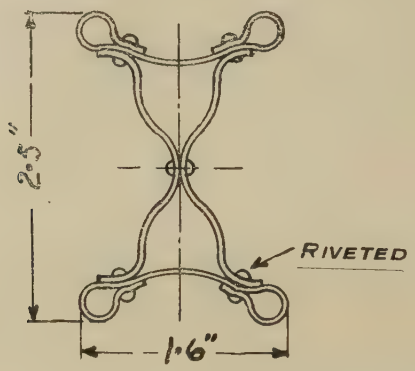


Fig. 12.—Cycle Rim, Avro Steel Spar Specimen.

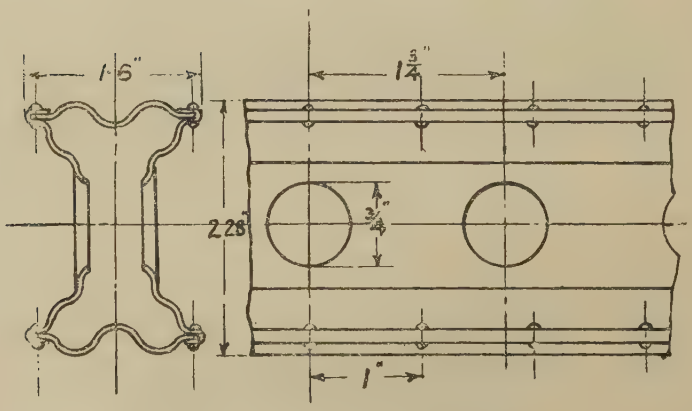


Fig. 14.—Boulton and Paul Avro Spar Specimen.

square inch in the compression boom at failure when the relatively flat boom strip buckled.

In the design, Figs. 13 and 14, Messrs. Boulton & Paul over-

came to a large extent, in a very simple manner, the weakness of the free lips by folding the edges of the web strips over the free edges of the corrugated booms, and then by riveting the three thicknesses of material together.

In the earlier test specimens the uncorrugated central portion of the webs at the neutral axis was lightened, and then stiffened by flanging the holes, as shown in the sketch. This method of stiffening did not prove very satisfactory; the webs were rather weak, and showed a strong tendency to come together when the test specimen was loaded. The deflection of the specimen was, consequently, much greater than was calculated, and with the relatively large end load the additional stress

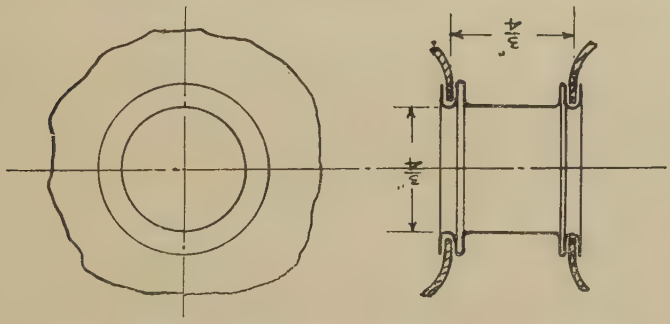


Fig. 15.—Mode of Bracing Webs of Boulton and Paul Steel Spars.

due to the end load bending-moment increased rapidly, producing failure at a load factor of 6·2 in the case of a test specimen which was 7 per cent. lighter than the standard Avro wooden front spar, although the maximum fibre stress developed in the compression boom had the high value of 55·4 tons per square inch. The spar usually failed by buckling at the compression boom, starting from the riveted edges.

These webs are now braced together, as shown in Fig. 15, with very light gauge tubes, which act as distance pieces between the webs by means of shoulders bumped up on the tubes as shown, giving a much stiffer spar and wing.

The earlier main-plane spars, designed and built by Messrs. The Steel Wing Co., for all-metal wings for the B.E.2d and the Bristol M.R.1 aeroplanes, in 1917 and 1918, were in two portions, each consisting of a pair of steel channels connected by riveting to a continuous web with vertical corrugations of depth equal to the width of the channels.

In the M.R.1 machine the two parts of the spar were held apart by saddle plates to which the ribs were attached, as shown in Fig. 44 of the M.R.1 wing.

In the B.E.2d wing the two portions of the main spars were held apart by a continuous steel strip, blanked out and riveted to the spar, as shown in Fig. 17a. Attention is drawn specially to this light bracing on the booms with its slight stiffening corrugations at 5 inches pitch, because in all the cases where a similar type of spar construction was tried, spars with four main members, angles, channels, etc., at the corners, connected together with some form of bracing on booms or webs, and especially where the spar was subjected to combined lateral and end loading, it was found that the bracing in the compression boom slackened and sagged and added relatively little or nothing to the strength of the spar. An example of this type of construction applied to an Avro spar specimen is shown in Fig. 16.

The maximum stress developed in these flat-sided channels, $\frac{3}{8}$ inch deep by $\frac{5}{8}$ inch wide, with rounded corners and edges. seems to be about 30 tons per square inch with material of higher elastic limit.

Successive modifications are shown in Figs. 17b and 17c, showing a continuous steel strip with longitudinal corrugations on each boom, and with the lightened webs forming what still appear to be corner channels, with the result that the Avro spar shown in Fig. 17c, 22 per cent. heavier than the Avro wooden front spar, gave at failure a load factor of 8·62 or 44 per cent. greater than the specified factor 6. This design of spar has also given excellent results in static tests

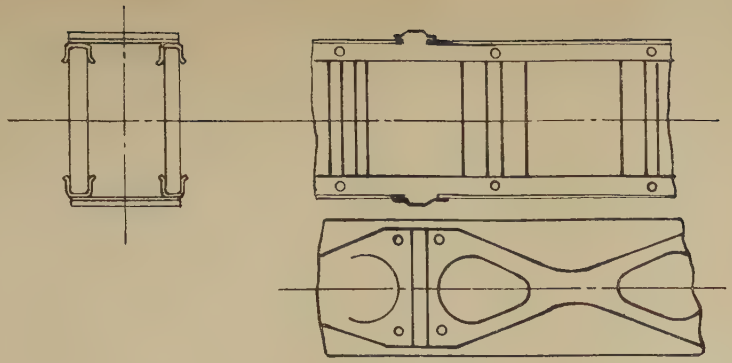


Fig. 17a.

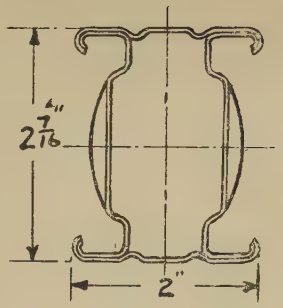


Fig. 17c.

Figs. 17a, 17b, and 17c.—Sections of Avro Steel Spar Specimens by Messrs. The Steel Wing Co.

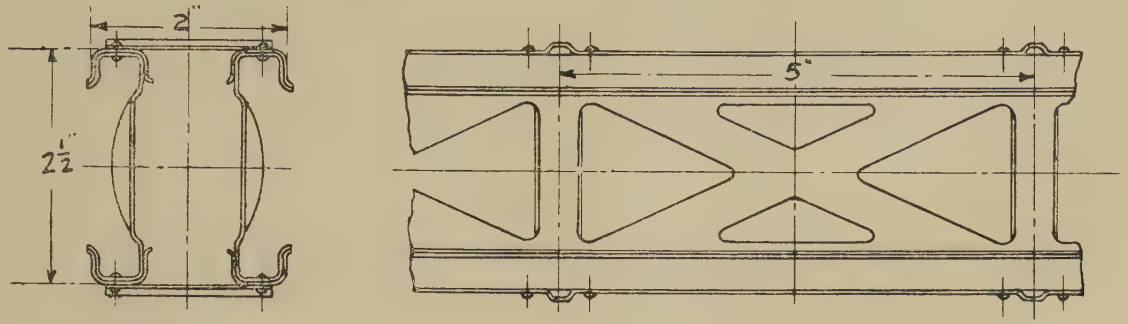


Fig. 17b.

on the complete wing structures and in continued flight tests with frequent landings of the aeroplane.

The thin steel-lattice web ·018 inch thick was weak in shear, resulting in the combined loading test in an increased fibre stress due to the end load bending-moment, and thus reducing the load factor.

A later development of this type of construction, shown in Fig. 18, has more curvature of the strips, especially at the overhung lips. A modification of this design had a weight 24 per cent. greater than the standard wooden spar, and gave a load factor of fully 9·5 or 58 per cent. greater than the specified load factor 6. The maximum stress developed at failure was 40 tons per square inch, the elastic limit of the material being 37·5 tons per square inch, and the yield stress 54 to 60 tons per square inch. Failure commenced by a buckling of one of the overhung lips, this buckling extending to the flange proper and to the webs.

This type of design with overhung lips at the maximum distance from the neutral axis, and with a slightly heavier section than the wooden spar, gives naturally a high value of the Euler crippling load and a high moment of inertia I, with a low fibre stress for a definite applied load. For example, at a load factor of 8 the maximum stress would only be about 31·5 tons per square inch, and at the specified load factor of 6 the maximum stress is only 23 tons per square inch.

Messrs. Bruntons, Musselburgh, and Messrs. Singer, Clydebank, in conjunction with Major J. Goodman, designed and constructed a considerable number of Avro spar specimens.

Fig. 19 represents a spar with webs blanked out to a lattice form, and with the vertical and diagonal members of the lattice stiffened by embossing. These webs are riveted to the corrugated booms by eyelets, and the overhung free lips of the booms are turned down, making the whole spar into a system of corner channels with lattice webs and continuous corrugated booms, and may, therefore, be compared with the equivalent

design by Messrs. The Steel Wing Co. The spar was too wide and too heavy, being 50 per cent. heavier than the wooden spar. It withstood a 65 per cent. greater load factor than the 6 specified, and developed only 31·9 tons per square inch at

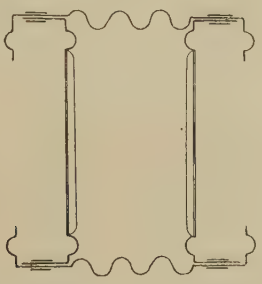


Fig. 19.—Avro Steel Spar Specimen of Early Type by Messrs. Bruntons.

failure, and shows the weakness and waste of material at the edges of the booms.

The spar specimen shown in Fig. 20 is built up of two similar pieces, which overlap at the booms, giving double thickness of material. In the actual spar specimen the two halves of

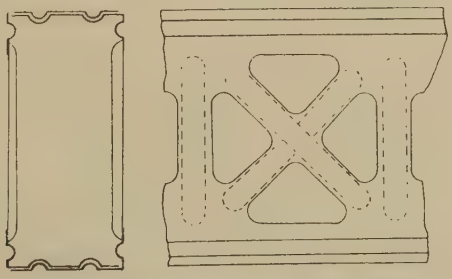


Fig. 20.—Avro Steel Spar Specimens of Later Type by Messrs. Bruntons.

the boom were connected together by soldering, and in spite of the irregularities of the corrugations the specimen, which weighed 0·50 lbs. nett per foot or about 0·60 lbs. per foot including the solder, against the standard 0·58 lbs. per foot,

withstood a load factor of 8·1 against the 6 specified, and developed a maximum fibre stress of 47 tons per square inch in the compression boom at failure, with material having an elastic limit of 43 tons per square inch, and an ultimate stress of 55 tons per square inch. The specimen was only 1·1 inches wide and was probably weak laterally. Failure occurred by buckling of the compression boom. The yield point of the material must have been about 47 tons per square inch, and consequently the specimen, in any case, could not have developed a stress much greater than 47 tons per square inch. This spar specimen represents a successful attempt to get rid of the free edges in the boom.

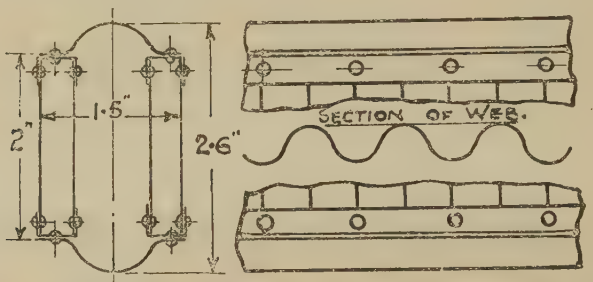


Fig. 21.—Channel Type of Avro Steel Spar Specimens by Messrs. Singer Manufacturing Co.

Figs. 21 and 21a show a design by Messrs. The Singer Manufacturing Co. utilising steel channels braced together with deeply-domed boom strips, and continuous webs with vertical corrugations. This design was developed independently, and avoids the weak features of the thin steel channels by bringing these channels closer to the neutral axis of the spar. The specimen was naturally heavy, being 29 per cent. heavier than the wooden spar specimen, but developed a maximum stress at failure of about 39 tons per square inch, with a load factor of 6·9 against the 6 specified. The elastic limit of the material was about 33 tons per square inch, and the ultimate stress 49 tons per square inch.

The box type spar with continuous corrugated booms and lattice webs shown in Figs. 22 and 22a was produced by the Empire Art Metal Co., U.S.A., and is of a size similar to that of the Avro spars. Free edges are avoided on the booms by making the spar in two parts—one boom and one lattice web forming a piece. The halves are riveted together, forming a very simple and effective construction for the smaller-sized main-plane spars.

Shear Tests on Avro Steel-Spar Specimens.

In general there was little difficulty in making the all-metal Avro spar specimens strong enough in shear. The maximum shearing force on the front spar in the inner bay at a load

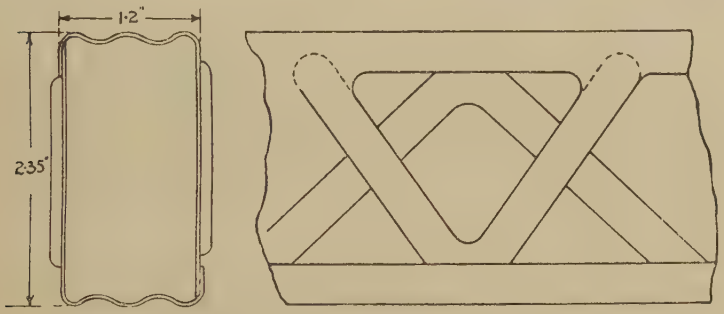


Fig. 22.—Small Steel Spar by Empire Art Metal Co., U.S.A.

factor of 6 is approximately 500 lbs. Many of the lightened webs were strong enough in shear, but they gave too large shear deflections for spars with the large end loads in the Avro 504 K.

As a definite illustration of the increased shear deflection in a spar specimen with continuous webs it will be instructive to study Fig. 23, where a comparison is given of the load-deflection curves obtained from bending tests on two short lengths of spar specimens illustrated in Fig. 17c, one with continuous web 0·015 inch thick, and corrugated longitudinally, the

other with lattice web 0·018 inch thick as shown. The lattice web was actually 6 per cent. heavier than the continuous web. At the proof load, when the shearing force was 500 lbs., the shear deflections were 0·138 inch and 0·066 inch for the lattice and continuous web respectively. The

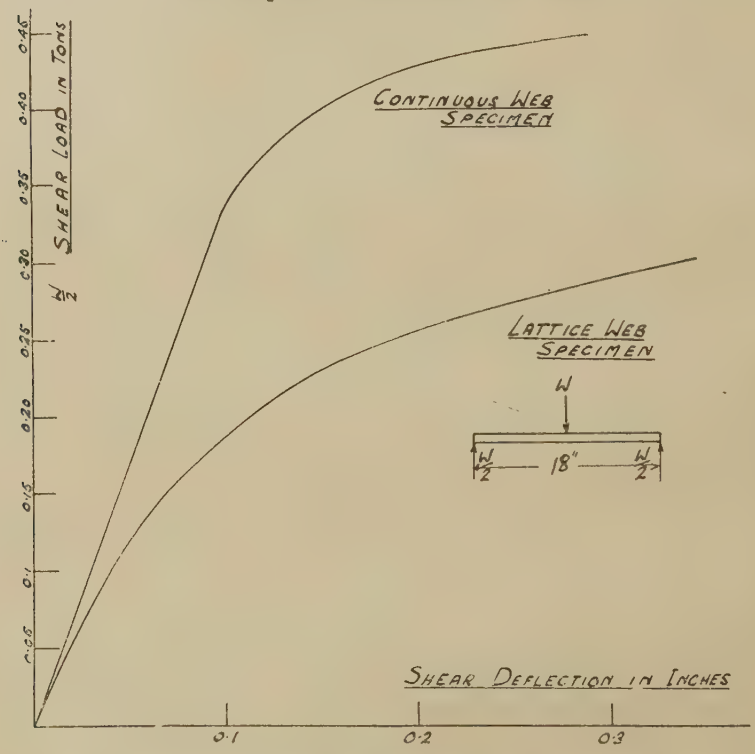


Fig. 23.—Shear Deflections for Spar Specimens with Continuous and Lattice Webs shown in Figs. 17b and 17c.

deflections were, therefore, in the ratio of 2·1 to 1, and the lattice web for the present purpose would appear to have an effective value of less than half that of the continuous web. Probably the same proportion would hold between a web with simple circular lightening holes and the continuous web.

Experiments on the influence of embossing the diagonals of a lattice web on the strength and stiffness of the spar were carried out on the spar specimen shown in Fig. 19. The spar specimen was first tested with the vertical lattice members embossed; a second test was then made on the same spar specimen after the diagonal members of the lattice web had been embossed. The embossing of the diagonal members raised the elastic limit of the spar from 15·1 to 18·8 tons per square inch, and the ultimate strength from 30·6 to 35·1 tons per square inch.

The stiffening of the diagonal members of the lattice web has raised the elastic limit of the spar by 25 per cent., and the ultimate stress and load by about 15 per cent.

All experience goes to prove that in these Avro spar specimens, if the design is relatively light, and if it is intended to develop a high fibre stress of the order of 60 tons per square inch or greater, attention must be paid to the stiffening of the webs, and no lightening holes should be permitted.

If the webs are continuous and rigid they will also take their proper share of the end thrust, and will to that extent relieve the stress in the compressive boom.

COMPARISON OF THE EXPERIMENTALLY DETERMINED CHARACTERISTICS OF THE VARIOUS DESIGNS, WITH THEIR PREDETERMINED CHARACTERISTICS.

Referring back to the pin-jointed strut with end thrust P, and lateral bending-moment M, as shown in Fig. 1, the Perry formula gives

$$f_c = \frac{P}{A} + M\left(\frac{Q}{Q-P}\right)\frac{y}{I} \quad \cdot \quad \cdot \quad \cdot \quad (2a)$$

as the relation between f_c the maximum stress developed and the loading M and P for the case of uniformly distributed lateral load. If the constants y, I, and Q are known for the various test specimens, and if the numerical relationship of

M to P is kept constant, the maximum stress f_c can be calculated for all values of P or M.

In Fig. 24 the graphs S_1, S_2, S_3 represent the relationship between the maximum compressive stress developed and the load P or the load factor for three different steel spar specimens

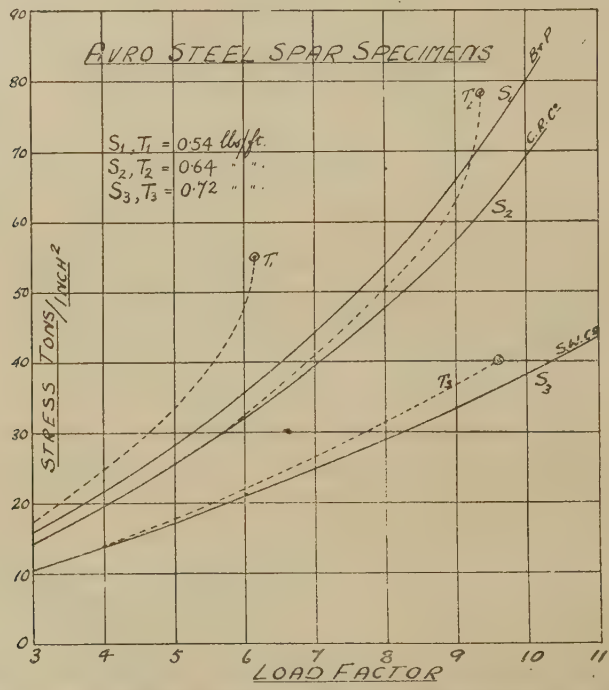


Fig. 24.—Avro Steel Spar Specimens. Load-Stress Characteristic Curves.

calculated on the assumption that E is 13,000 tons per square inch, and that the stress is everywhere within the elastic range.

S_1, S_2, and S_3, therefore, represent the ideal characteristics, and give the minimum stress which a definite loading will produce.

S_1 represents a Boulton and Paul specimen weighing 0·54 lbs. per foot.

S_2 represents a cycle rim specimen weighing 0·64 lbs. per foot.

S_3 represents a Steel Wing Co.'s specimen weighing 0·72 lbs. per foot.

The dotted curves T_1, T_2, T_3 show the actual load-stress characteristics obtained in each case respectively in tests to destruction of the three specimens.

In all three cases the actual experimental characteristic T lies above the calculated, ideal, characteristic S, showing that

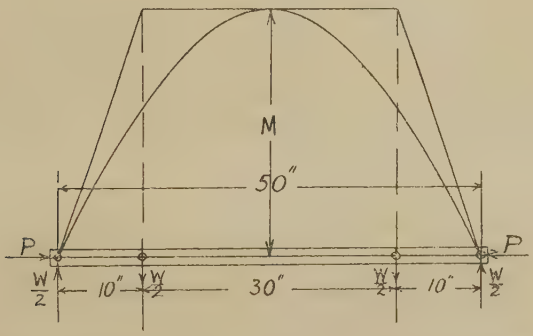


Fig. 24a.—Actual Transverse Loading on Avro Spar Specimens.

on test the stress developed for a given loading was greater than the stress as calculated by equation 2a. This increased stress is caused (a) by any lack of alignment of the specimen; or (b) because the end load P does not pass through the centroid of the section of the specimen; or (c) because the shear deflection of the specimen is appreciable; or (d) because the material in the specimen is stressed beyond the elastic limit; or, broadly speaking, because the deflection of the specimen was greater than that assumed in the formula 2a, giving rise to an increased stress due to the end thrust bending-moment $P\delta$.

In the actual tests the transverse loading was applied, as is shown in Fig. 24a, where equal loads W are concentrated at 10 inches distance from the ends of the 50-inch specimen, giving a uniform bending-moment M over the central 30 inches of the specimen, instead of the parabola for a uniformly distributed load.

If the maximum value M of the bending-moment is the same in the two systems of loading, then the maximum deflection for the concentrated loading is $\frac{71}{600} \cdot \frac{Ml^2}{EI}$, and for the uniformly distributed loading it is $\frac{5}{48} \cdot \frac{Ml^2}{EI}$, giving a deflection in the actual experiment of 13 per cent. greater than was assumed in equation 2a, or, making certain allowances such as for stiffness of loading boxes, etc., it may be assumed that in the tests the deflections due to the transverse loading were from 5 per cent. to 10 per cent. too great. This gives directly an increase of from 5 per cent. to 10 per cent. in the end load bending-moment stress $P\delta$, and will probably partly account for the curves T lying so far above S.

On the whole the experimental graphs T_2 and T_3 agree closely with their respectively calculated graphs S_2 and S_3 until, in the case of T_2, the material in the specimen is stressed beyond the elastic limit, and finally beyond the yield stress also, the specimen failing ultimately at a maximum compressive stress of 78 tons per square inch. The experimental spar T_3 only just reached the elastic limit of the material when secondary failure occurred.

The experimental spar T_1 failed directly by buckling of the lip of the compression boom, but indirectly because of the large deflection due to the weak webs; a high value of the maximum stress was reached, but for the same maximum stress the load factor at failure could be increased from its value 6·2 to 7.

The various spar designs may now be compared with one another by reducing each to the standard weight, and by comparing the maximum stress and load reached in each case with a single standard stress-load characteristic curve S. If all specimens were reduced in weight to the value 0·58 lbs. per foot, a good average value for the moment of inertia of the steel specimens would be 0·140 inch units; $y = 1{\cdot}25$ inches and E is assumed equal to 13,000 tons per square inch. The standard reference curve S has been calculated for these constants, and is plotted in Fig. 25.

The various maximum stress and load points obtained by experiment, when plotted in Fig. 25, give the curve L, the ordinates being, as previously, the actual maximum stress developed, but the abscissæ are now the actual load factor on test divided by R, where R is the ratio of the weight of the test specimen to the standard reference weight, 0·58 lbs. per

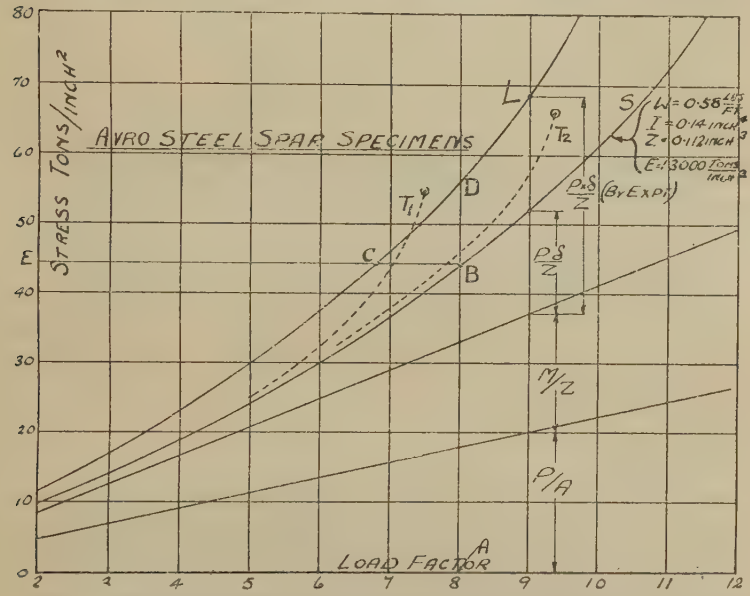


Fig. 25.—Stress-Load Characteristics for Steel Spar Specimens when reduced to a Common Weight per Foot Run.

foot run. The assumption is, therefore, that the new specimen, if altered in weight to 0·58 lbs. per foot run would, on test, develop the same maximum stress as formerly, and give a load factor modified proportionately to the alteration in weight of the specimen. Within the narrow limits through which most of the test results were adjusted, this assumption is fairly accurate.

The curve L in Fig. 25 has been drawn to represent the locus of these experimental points of maximum stress and load factor, due regard being paid to the value of each of these points.

Certain experimental points which lay to the left of L referred to designs which could obviously be improved, giving a better load factor, and possibly also a slightly higher maximum stress; certain points which lay to the right of L referred to designs which were constructed of material carefully heat treated and giving a high elastic limit and yield stress.

The curve L may therefore be regarded as the locus of the maximum stresses, which should not be exceeded in actual Avro steel spars. For example, if a load factor of 8 is aimed at, the maximum stress will have AB = 44 tons per square inch for its ideal value and AD = 56 tons per square inch as its extreme value, or a steel spar of standard weight designed to develop 44 tons per square inch should withstand a minimum load factor EC of 6·75, and under the best conditions a load factor EB of 8.

Spars developing a low stress at failure, and having for compensation a relatively high moment of inertia, should coincide more nearly with, or perhaps even lie to the right of the standard curve S, and those developing the higher stresses will probably coincide more nearly with the experimental locus L. The higher the elastic limit and the yield stress of the material, and the more stable the design of a spar, the flatter will be its stress-load characteristic. A good example is the test curve T_2, obtained from a Dunlop spar specimen specially heat treated after construction; the test characteristic of the same spar specimen before heat treatment is shown at T_1 (see also p. 201).

The equation of the experimentally deduced locus curve L may be taken as the original equation 2a, with Young's modulus E, averaging 9,000 tons per square inch instead of 13,000 in the standard curve S.

With this information about the characteristics of the spar near to failure, and knowing from the design what the failing stress will be, it should be possible to predetermine within narrow limits the actual stress-load characteristic of the speci-

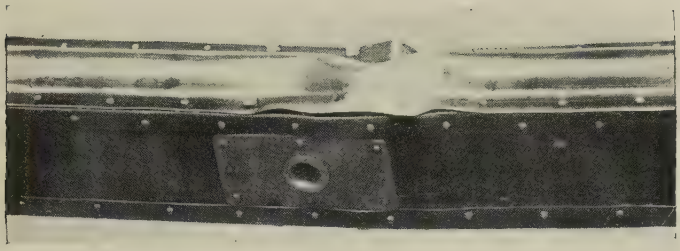


Fig. 21a.—Channel Type of Avro Steel Spar Specimen by Messrs. Singer Manufacturing Co.

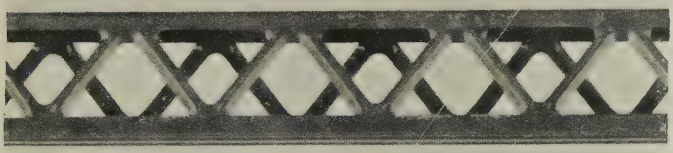


Fig. 22a.—Small Steel Spar by Empire Art Metal Co., U.S.A.

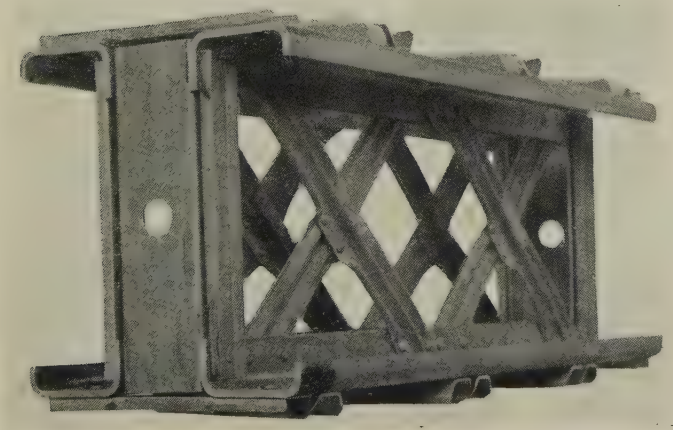


Fig. 27.—Duralumin Spar, showing Channel Bracing in Boom and Corrugated Bracing on Webs.

Fig. 29.—Duralumin Spar, showing Continuous Plate Bracing in the Booms.

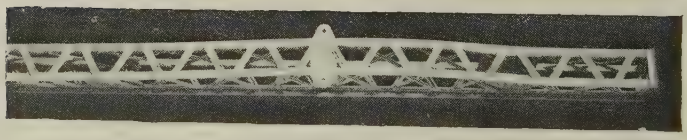


Fig. 30.—Lateral Bowing of Compression Boom of Spar, Tested under Combined Loading.

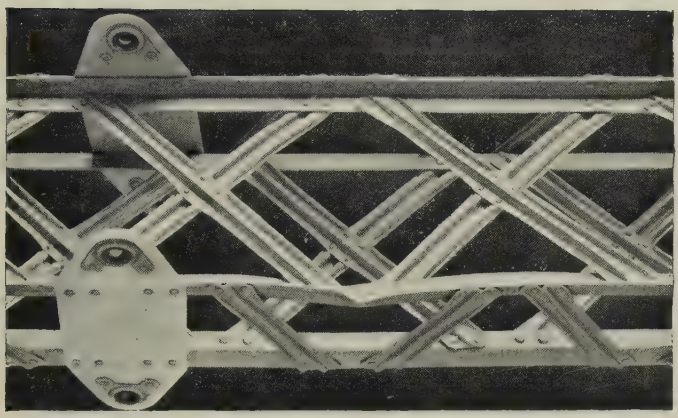


Fig. 30a.—Buckling of One Angle of Compression Boom after the Whole Spar had Bowed Laterally.

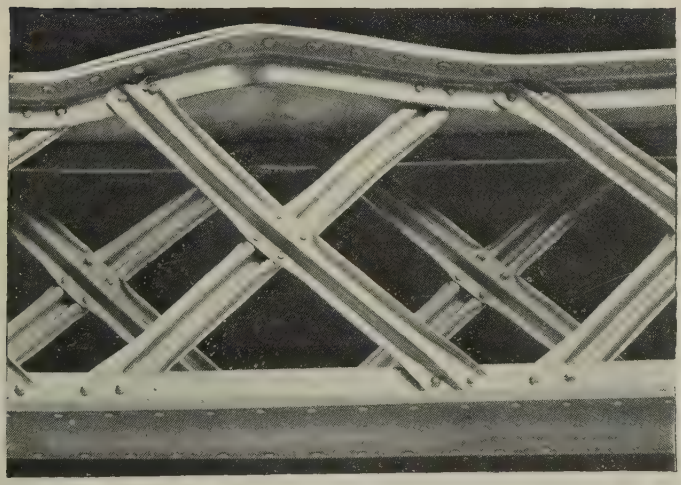


Fig. 31.—Buckling of Dished Plate and Angles of Boom in a Compression Specimen.

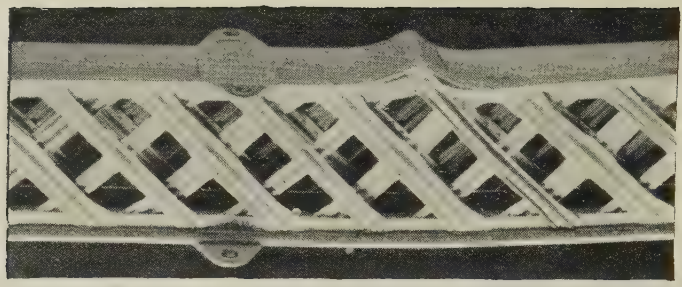


Fig. 32.—Buckling of Compression Boom of Specimen under Combined Loading.

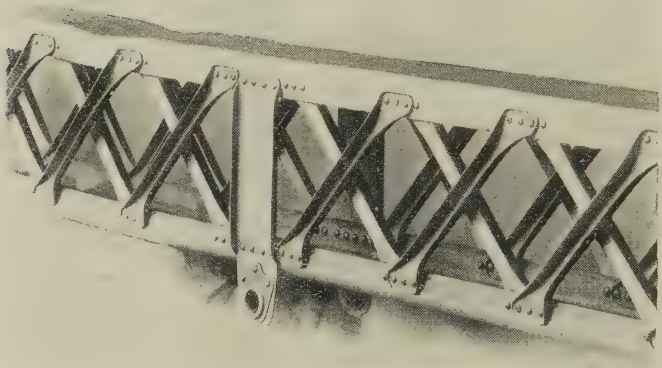


Fig. 33.—Heavier Duralumin Channel-Spar Specimen.

Fig. 34.—Lightest Section of Duralumin Spar for the Outer Bay of the Handley-Page V 1500 Machine.

men. The curves S and L can be drawn for the test specimen with E = 13,000 tons per square inch and 9,000 tons per square inch respectively, and assuming that the maximum stress developed will be approximately 50 tons per square inch, the experimental stress load curve will lie close to S, and will ter-

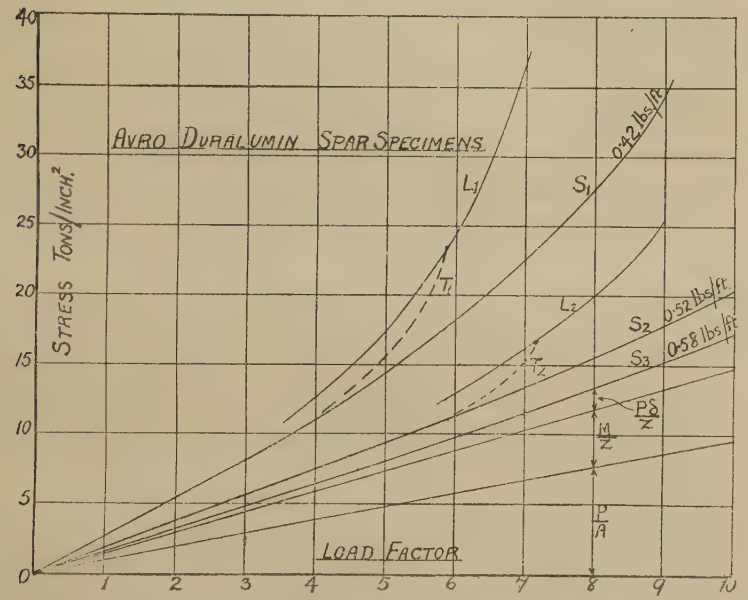


Fig. 26.—Stress-Load Characteristics for Avro Duralumin Front Spar Specimens.

minate on the 50 tons per square inch stress line, somewhere near to the point where that stress line cuts the curve L.

Analysis of Duralumin Specimens for Avro Front Spar.

A similar analysis of the duralumin Avro spar specimens is shown in Fig. 26. T_1 and T_2 are the experimental curves for two specimens weighing respectively 0·41 lbs. per foot and 0.52 lbs. per foot. T_1 is the design of Prof. Lea, and had its booms convex outwards; T_2 is illustrated in Fig. 7, and had its booms concave outwards.

S_1 and S_2 are the corresponding graphs calculated from equation 2a from the constants of the specimens, and assuming E to be 4,800 tons per square inch. S_3 is the calculated graph for a duralumin spar of standard weight and of design similar to S_2. The ends of the experimental curve T_1 and T_2 seem to lie on the curves L_1 and L_2, whose equations are those of S_1 and S_2, but with E equal to 3,000 tons per square inch and 2,800 tons per square inch respectively instead of 4,800 tons per square inch.

Comparison of Duralumin Spar Specimens with Steel and with Timber Spar Specimens.

A comparison of Fig. 26 for duralumin with Fig. 25 for steel will show the radical difference between the various stress components $\frac{P}{A}$, $\frac{M}{Z}$, and $\frac{P\delta}{Z}$ in the two cases. The following data have been obtained from the graphs in these two Figs.:—

Table I.

Spar Specimen in each case 0·58 lbs. per foot.	Load Factor	Developed Stress. Tons per square inch.				Percentage of total stress.		
		Total.	$\frac{P}{A}$	$\frac{M}{Z}$	$\frac{P\delta}{Z}$	$\frac{P}{A}$	$\frac{M}{Z}$	$\frac{P\delta}{Z}$
Calculated Graph S_3 (Fig. 26) Duralumin Spar	6	9·6	5·75	3·06	0·79	60·0	31·8	8·2
	9	15·2	8·62	4·59	1·99	56·7	30·2	13·1
Calculated Graph S (Fig. 25) Steel Spar	6	29·9	13·3	11·4	5·2	44·5	38·1	17·4
	9	52·1	20·0	17·2	14·9	38·4	33·0	28·6
Experimental Graph L_3 (Fig. 26) Duralumin Spar	6	10·5	5·75	3·06	1·69	54·7	29·2	16·1
	9	18·0*	8·62	4·59	4·79	47·9	25·5	26·6
Experimental Graph L (Fig. 25) Steel Spar	6	37·5	13·3	11·4	12·8	35·5	30·4	34·1
	9	68·5	20·2	17·2	31·1	29·5	25·1	45·4

* The design of duralumin spar with concave booms would probably not develop more than 18 tons per square inch, and hence the maximum stress has been taken as 18 and not as 18·4 tons per square inch as in graph L_3, Fig. 26.

It will be seen that the stress due to end-load bending-moment in the case of the duralumin Avro spar specimen is, even at high load factors, relatively only one-half as great as the corresponding stress in the steel spar, whilst the direct stress component $\frac{P}{A}$ is relatively greater in the case of the duralumin spar than in the steel spar. This difference is due to the relatively better value of Z, the modulus of section in the case of the duralumin spar. For the design shown in Fig. 7 with a concave boom and lattice web and with the standard weight of 0·58 lbs. per foot run, the Z for duralumin is 0·382, against 0·112 for the steel spar. Other constants are as follows:—

TABLE II.

Ratio.	Density.	I.	E.	I.E. from actual test specimens
Duralumin / Steel.	$\frac{2\cdot8}{7\cdot8} = \frac{1}{2\cdot78}$	$\frac{0\cdot382}{0\cdot112} = \frac{3\cdot43}{1}$	$\frac{4,800}{13,000} = \frac{1}{2\cdot71}$	$\frac{3\cdot43}{2\cdot71} = \frac{1\cdot26}{1}$

The duralumin spar has, therefore, a 26 per cent. advantage over the steel spar, and hence the duralumin spar can only be equalled by a steel spar developing a very high stress. Table I gives for a load factor of 9, with standard spars, a stress of 18 tons per square inch in the duralumin against about 68 tons per square inch in the steel.

In the timber spar the load factor may be taken as 6, and to equal the strength of the timber spar, the duralumin spar must develop a stress of 10·5 tons per square inch, and the steel spar must develop a stress of 37·5 tons per square inch, both values well within the reach of very mediocre designs.

COMPARISON OF AVRO SPARS WITH THOSE OF TYPICAL SINGLE BAY AND TWO BAY MACHINES UP TO 3,300 LBS.

Take for purposes of comparison the inner bay only of the machines. In the Avro the inner bay is 75 inches long; the

front spar is $2\frac{1}{2}$ inches deep, and the rear spar 2 inches deep. Hence $\frac{l}{d} = 30$ and 37·5 for the front and rear spars respectively. The spars are, therefore, very shallow, and hence the ratio $\frac{Q}{P}$ for these spars is 12·4 and 5·7 respectively for front and rear spars, where Q is the Euler failing load for a free-ended strut and P is the end load. These values for $\frac{Q}{P}$ are exceptionally small, and are much smaller than is usual in either a two bay or a single bay machine.

TABLE III.

Ratio.	Front Spar.			Rear Spar.		
	Avro.	Two-bay Machine.	Single-bay Machine.	Avro.	Two-bay Machine.	Single-bay Machine.
$\frac{l}{d}$	30	22 to 15	27 to 18	37·5	24 to 18	30 to 21
$\frac{Q}{P}$	12·4	98 to 19·5	54 to 15·5	5·7	55 to 9	26 to 12

The ratio of the unit end load to the unit bending-moment in the Avro machine is on the average slightly less than in other two bay machines.

The Avro spars were, consequently, more difficult to design in metal, and especially in steel, than would have been the case for a machine with a smaller ratio of length of bay to depth of spar. For that reason certain of the spars supplied for the Avro could probably be employed without alteration for other and heavier machines, and in other cases the chief modification necessary would consist of a stiffening up of the webs of the spars to allow of their construction in sizes from 3 inches to $4\frac{1}{2}$ inches deep.

It should, therefore, be possible to standardise certain of the more stable designs, keeping for example the section of the

booms constant, and varying the depth of the webs to suit the varying aerofoil wing sections, and if an exceptionally strong spar of small depth were required it should be possible to mount two standard sections side by side and brace them together to form a single spar. Such a twin spar would have several advantages for the attachment of interplane struts, etc.

LARGER-SIZED MAIN PLANE SPARS SUITABLE FOR THE VIMY AND HANDLEY-PAGE V 1500 MACHINE, ETC.

In addition to the experiments carried out on the main planes for smaller- and medium-sized machines, a considerable amount of work has been done on the development of metal construction for the largest types of aeroplanes.

These experimental spars may again be subdivided into (a) duralumin and (b) steel.

Following on their work with the small Avro spars, Messrs. Vickers & Co. Ltd. designed and constructed a large number of duralumin spar specimens for their Vimy aeroplane, and for the Handley-Page V 1500 aeroplane.

Spar specimens of length equal to the distance between the points of contraflexure in the various bays of the main planes were tested in a similar manner to the Avro specimens, under combined transverse and end loading. Other specimens of length equal to the distance between consecutive compression ribs were tested as ball-ended struts.

The following data (Table IV) for the front spar in the upper wing of the Handley-Page V 1500 machine may be taken as typical of the requirements for these larger specimens. The loading given corresponds to four times the unit load for normal flight.

The overall dimensions of the wooden spar everywhere were approximately 4 inches wide by 8 inches deep. It was, therefore, decided to keep the metal spars also of constant overall dimensions, approximately 4 inches by 8 inches, and to experiment with spar specimens of a type similar to that already illustrated in Fig. 8 for the Avro duralumin spar.

TABLE IV.

Position of Specimen.	Test Specimens.					Approximate weight of Wooden Spar in lbs. per ft. run.
	Combined Loading with Pin Ends.			Ball End Tests.		
	Length of Specimen between Roller Centres.	End Load in lbs.	Maximum Transverse B.M, in ft. lbs.	Length of Specimen between Ball Centres.	End Load in lbs.	
Outer bay	9′ 3″	12,300	3,600	8′ 3″	12,300	1·50
1st Inter	8′ 10″	32,500	3,480	7′ 6″	32,500	2·13
2nd Inter	7′ 5″	51,500	2,400	5′ 3″	51,500	2·50
Inner bay	7′ 2″	79,000	2,160	6′ 2″	79,000	3·60

By employing angles or channels for the main members of the spars it was possible to keep the length of side of these members constant, and by varying the thickness of metal, to get suitable strengths and also weights per foot run for the loading in the different bays of the wings. Consecutive portions of the main-plane spars could also be butted together and connected simply to form a complete main-plane spar. The angle- or channel-design was also chosen on account of the ease with which the wing fittings could be attached.

With this type of design, on account of the size of the spar, and the specified weight per foot run, it was necessary to use thin sections of duralumin, and, in order to avoid secondary flexure of the angles the ratio of side of angle to thickness of metal had to be kept within 7 to 1. By keeping to this ratio of side to thickness in the outer bays where the loading is relatively small, and then by keeping the sides of the angle constant, the thickness of the angles in the inner bays would have exceeded 0·2 inch.

This is the maximum size for drawn duralumin section, and, consequently, for the heavier loaded bays a channel section was used for the main members of the spars instead of the plain angle section. This channel could have a width considerably greater than seven times its thickness without secondary failure occurring.

These spar specimens with angle or channel main-members had a lattice-web bracing composed of a double Warren system, each member in the bracing being riveted to the angle or channel members. The members of one Warren system were also riveted to those of the other system where they crossed at the

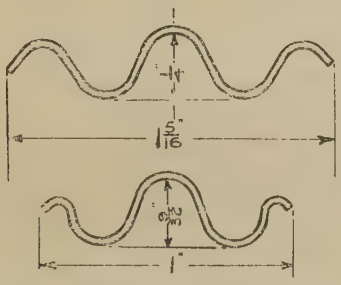


Fig. 28.—Sections of Corrugated Bracing Members for Web and Boom.

neutral axis of the spar. A similar simple Warren system of short bracing members was employed with the booms.

Web- and boom-bracing members of simple channel-section, $1\frac{1}{2}$ inches wide by $\frac{1}{2}$ inch deep, with flat sides, Fig. 27, and also of the corrugated type illustrated in Fig. 28, were employed in the earlier experiments.

An alternative modification for the boom bracing on the heavier spar sections consisted of a continuous duralumin plate riveted to the angles and dished out in a similar manner to the Avro duralumin spar illustrated in Fig. 7. An example of this type of spar is shown in Fig. 29.

Typical failures of these spars are shown in the following: Figs. 30, 30a, 31, and 32.

Ball-End Strut Specimens.

These were tested in lengths equal to the distance between consecutive compression ribs. The spar specimens with lattice-boom bracings all failed initially by bowing sideways as a whole. In one case this was followed at once by the lateral collapse of one of the booms due to the weak bracing. This collapse of the boom bracing also occurred at a later stage in another case. In most of the other specimens the final failure occurred by the buckling of one of the angles on an unsupported length.

On plotting the maximum stress developed $\frac{P}{A}$, to a base of $\frac{L}{K}$, it was found that the limiting stress for small values of $\frac{L}{K}$ was approximately 18 tons per square inch.

The specimens with continuous dished-plate boom bracing mainly failed initially by bowing sideways as a whole, followed by buckling of a short length of plate and angle where unsupported by the web-lattice members. Two specimens, which failed initially by local buckling of the plate and angles of a boom, gave relatively high values for the maximum stress $\frac{P}{A}$.

From a consideration of the stress, $\frac{L}{K}$ graph, the limiting stress in this type of spar seemed also to be about 18 tons per square inch.

Combined Bending and End Compression Specimens.

The specimens with lattice bracing in the booms failed mainly by lateral bowing of the compression boom with collapse of the bracing on the booms or of one angle in the compression boom. This type of failure is very similar to that already described at the commencement of the paper in connection with large steel spars, and also with the small Avro spars with lattice-boom bracing, and confirms the information that such a type of boom bracing is relatively weak unless very heavy. The

maximum stress developed varied from 13 tons per square inch to 18 tons per square inch, agreeing with those obtained in the ball-end compression tests.

The specimens with dished-plate bracing in the booms failed mainly by buckling of short lengths of plate and angles on the compression boom at maximum stresses, varying from 15·2 tons per square inch to 18·8 tons per square inch. In one specimen the dished-plate alone buckled in a short length between rivets, pointing to too wide spacing of the rivets. In these spars the lateral failure of the lattice booms is replaced by buckling in the direction parallel to the major axis of the spar.

Stress Due to End Load Bending-Moment.

In the combined loading tests the bending-moment stress due to the end thrust P at failure, in the case of those specimens which developed a maximum stress of approximately 18 tons per square inch, was only from 9 per cent. to 14 per cent. of the total stress developed, although the actual deflections of the spars on test were considerably greater than the calculated deflections.

These large duralumin spars are, therefore, similar to the small Avro duralumin spars where the proportion of the stress due to end-load bending-moment is relatively small.

FURTHER SERIES OF HANDLEY-PAGE SPAR SPECIMENS IN DURALUMIN.

The results obtained from these preliminary Handley-Page test specimens were so promising that a further series of spar specimens were prepared by Messrs. Vickers and tested with the loading specified in the previous Table IV.

These specimens were all 4 inches wide by 7·2 inches deep, measured over the booms, the three heavier sections, as shown in Fig. 33, had plain channel booms 4 inches wide by 1·28 inches deep by 0·142 inch, 0·180 inch, and 0·25 inch thick respectively;

whilst the lightest section had also continuous-plate booms, 0·075 inch thick, and corrugated as shown in Fig. 34.

The web bracing in these spars is of the double Warren type, the members being of plain channel section 0·6 inch wide by 0·4 inch side by ·035 inch thickness of material, attached by rivets to the free edges of the booms. In order to withstand the heavy shearing forces at the ends of the specimen, the web lattice was duplicated or triplicated when necessary. The weight of the web-bracing member was approximately 0·31 lbs. per foot, and represented from 8 per cent. of the total weight in the case of the heaviest spar to 19 per cent. in the case of the lightest spar.

In the tests under combined bending and end load the lightest specimen with the 0·075 inch corrugated boom failed at a maximum stress of 14·7 tons per square inch, by buckling of the free edge of the booms. The central corrugation in the compression boom also showed signs of waviness. The lightest channel section spar with ·142 inch material failed, as shown in Fig. 33, by buckling of the flat boom on a length equal to the pitch of bracing.

The two heavier channel spar specimens failed by shearing of the webs; the lighter channel-section also showed signs of web failure. All the channel-section spar specimens developed a maximum stress of approximately 16·5 tons per square inch at failure, and each of the four specimens developed at failure a load factor of approximately 4·5 against the 4 specified. This type of large duralumin spar specimens may, therefore, be regarded as satisfactory.

The corrugated spar specimen, Fig. 34, could probably be materially improved by omitting the central of the three longitudinal corrugations and by simply dishing the booms as shown in the duralumin Avro spar, Fig. 7. The developed width of the boom plate could thus be reduced and for the same weight of spar the thickness of the plate could be increased from 0·075 inch to, say, 0·090 inch. The free lips of the

booms would be materially strengthened by the thickening of the material.

The material in the central corrugation of this boom is not nearly so effective for withstanding end load as the side corrugations; it is supported in a " springy " manner along its two edges from the side corrugations and will offer less resistance to transverse bowing under end load than would the side corrugations, which are supported on one edge at least by the web bracing.

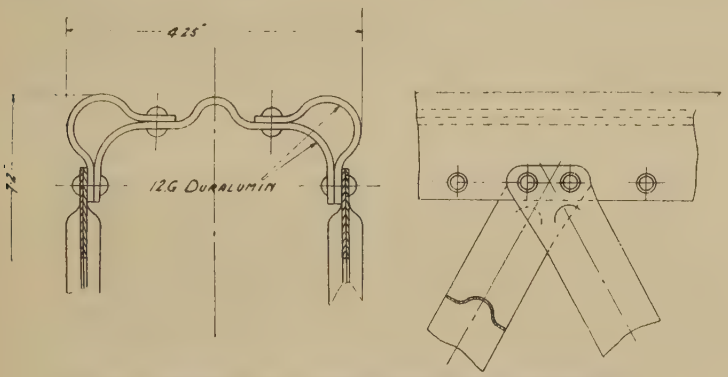


Fig. 34a.—Duralumin Spar Section, Messrs. Wm. Beardmore & Co.

An alternative method of stiffening up the central corrugation is by duplicating the boom at the outer corrugations, as shown in Fig. 34a in the duralumin spar constructed by Messrs. William Beardmore & Co., Dalmuir.

This duralumin spar specimen for the inner bay of the Handley-Page aeroplane weighed only 3·2 lbs. per foot, and developed a stress of 20·8 tons per square inch at failure, with a load factor of 4. This high stress compares favourably with the 18 tons per square inch usually developed in duralumin spars, and indicated that the whole boom was very rigid.

The question of the number of corrugations in a wide compression boom or, in other words, the method of stiffening of a wide plate, is of great importance, and offers a wide field for experimental research. It appears probable that (a) the

number of corrugations should be kept as small as possible, and (b) the depth of the corrugations should be such that the radius of gyration normal to the plate is large enough to prevent bowing of the stiffened boom on a length equal to the pitch of the web bracing.

Influence of Web Bracing in the Larger Duralumin Specimens.

With the web bracing shown the maximum fibre stress due to the bending-moment produced by the end thrust varied from

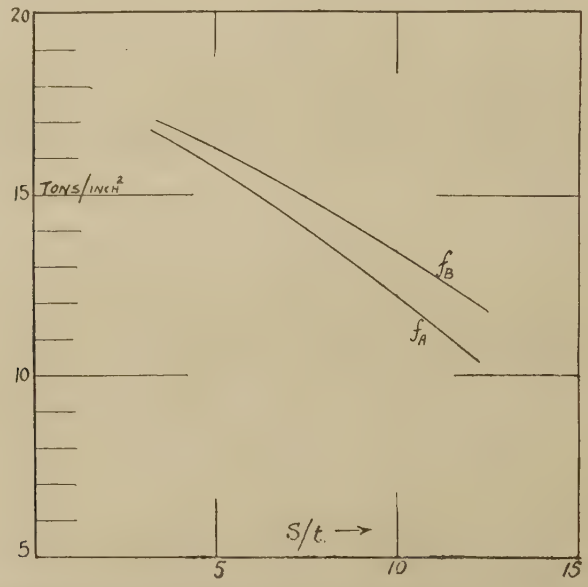


Fig. 36.—Failing Stress at Points A and B on Free Lip, Fig. 35, for Varying Ratios $\frac{s}{t}$.

7 per cent. to 17 per cent. of the total stress 16·5 tons per square inch at failure in the case of the specimens with plain channel booms. In the case with the 17 per cent. component of the stress the central deflection of the specimen was 0·87 inch, the deflection due to the transverse bending-moment making up exactly one-third of that amount. Two-thirds of the actual

deflection was, therefore, due to the bowing of the web bracing under shear forces and to the end thrust.

A stiffening of the web bracing, although probably advisable from a consideration of the shear forces alone, would not materially affect the stress due to the end-load bending-moment. Any stiffening of the web bracing, however, would mean an increase in the weight of the bracing beyond the present 8 per cent. to 19 per cent. of the weight of the whole spar, and it is, therefore, problematical whether the increased weight of a spar would withstand a correspondingly equivalent loading.

Since these bracing members are not loaded axially the compression members will bow as a whole considerably before complete failure occurs by buckling. The free lips of these members will be partly in tension, and are, therefore, to a great extent free from secondary failure.

Secondary Failure of Flat Surfaces in Duralumin Spar Specimens. Strength of Free Lips.

An investigation of a number of cases of duralumin spar specimens with free lips, of the type shown in Fig. 35, where the ratio $\frac{s}{t}$ varied from 5 to 12, and where the spar failed through buckling of the free lip of the compression boom under combined loading, shows that the stress developed in the free lips at failure varied as shown in Fig. 36 at the two sides A and B of the flat portion of the free lip.

MAIN-PLANE SPAR DESIGN: GENERAL CONCLUSIONS.

The essential requirement in these spars is maximum moment of resistance,

$$M = f\frac{I}{y} = f \times Z.$$

$$\text{Also } M = \frac{IE}{R},$$

whether the design is for simple bending or for combined bending with the end load or for simple struts.

All the experiments on built-up specimens prove that it is very difficult to avoid unsupported surfaces at the junctions of the several parts, and that failure of the specimen usually commences at these surfaces or, in other words, the strength of the whole specimen is limited by the buckling strength of a partly supported, overhung portion of the spar specimen. The number of separate pieces in the section, and especially in the booms, should therefore be kept to a minimum.

Designs with the booms all in one piece are probably preferable to those with corner members (angles, etc.) braced together by lattice members or even by a single continuous corrugated plate.

A spar with booms formed from a single piece such as a longitudinally corrugated plate may have a smaller moment of inertia I_{yy} about the vertical axis of the spar than one of equal weight per foot run with relatively heavy angles at the corners, and should have a greater tendency towards lateral failure, but this tendency is resisted by the rib connections between the front and rear spars of the wings. I understand that such a lateral failure of the two spars or of the wing as a whole is most unlikely.

In metal design of the complete wing it is necessary to incorporate a stiff leading-edge, if the wing is to be transportable without elaborate packing. Strength alone of the leading-edge is insufficient. Such a stiff leading-edge in the wing greatly supports the front spar against lateral failure, and may with profit be considered as an additional main-plane spar, especially if the front main-plane spar is constructed of two narrow spars side by side for convenience in attaching the interplane strut and wiring fittings at the neutral axis of the spar. As already explained, this division of the main-plane spar may considerably weaken the spar in a lateral direction under the large end thrust.

In built-up spars of the larger sizes the attachment of the web and boom bracing calls for very special jig work or for

highly skilled workmen. This bracing, if redundant, and composed of short members made of high tensile material, is almost certain to be initially stressed, and under load the forces are not equally divided among the members (say between the two webs of the spar), and early failure is certain to occur. Any lattice-bracing member should probably be capable of withstanding thrust as well as pull.

Manner of Failure Under Compressive Stresses.

One can probably predict the direction of failure of a single member, but when the member, such as a boom, is built up of several members riveted together it becomes a difficult matter to predict the direction of the failure, and hence to guard against it.

The condition for failure may possibly be stated as follows:— All sections under thrust tend to set themselves, to bow or to deflect, in such a direction that the moment of inertia of the section is diminished and the resistance to bowing decreased. If I is the moment of inertia and y the deflection, then $\frac{dI}{dy}$ is negative, and the weaker the section the greater will be the deflection under end load or under an equivalent transverse system of loading in the direction of the deflection.

By applying a transverse system of loading to a short length of the boom section under consideration it may be possible to determine in a simple manner the best of a number of forms of section for a given case.

METAL RIBS, AILERONS, AND WINGS.

Experiments on metal ribs have proved that there is no difficulty in making the ribs sufficiently strong to support the loading. In the smaller machines there is considerable difficulty in producing metal ribs as light and stiff as the wooden ribs, which are usually remarkably rigid and strong. Duralumin ribs for the Avro 504 K machine were as light as, whilst steel ribs for the same machine were slightly heavier than, the

standard wooden ribs. The simplicity of these standard wooden Avro ribs is seen from the composite wing shown in Fig. 39.

A number of types of steel ribs, by Messrs. The Steel Wing Co., built up of channel-section with corrugated web pieces are shown in Figs. 37 and 38. The lighter ribs shown in Fig. 37 were not very rigid; the channel-section developed "kinks," giving a weak trailing section to the rib. The pressed-steel ribs, built up in three portions, are shown in Fig. 38. The portions of this rib butt closely up to the steel spars, and are attached to them by the saddle plates shown in the figure.

Steel wings designed and constructed by Messrs. The Steel Wing Co. are shown in Figs. 39 to 41 and 43. A portion of an Avro composite wing with steel spars, as illustrated in Fig. 17b, and with standard wooden ribs, is shown in Fig. 39. An all-steel Avro wing with aileron is shown in Fig. 40; whilst Fig. 41 shows a later construction of Avro wing with rolled-steel spars, as illustrated in Fig. 17c, and with pressed-steel ribs.

One of the earliest types of all-metal wings constructed by Messrs. The Steel Wing Co. was for the B.E.2d aeroplane. The construction was similar to that shown in Fig. 42. The main spars are of the type illustrated in Fig. 17a.

A view of the Bristol M.R.1 machine, probably the first all-metal aeroplane in this country, is given in Fig. 42. This biplane was constructed by Messrs. The British and Colonial Aeroplane Co., Bristol, the main planes being designed and built by Messrs. The Steel Wing Co. A view of the steel wing is given in Fig. 43. The fuselage of this machine is built of hard-rolled aluminium sheets stiffened on the inside with other transversely corrugated sheets; the struts are of steel tubing.

Static Tests on Steel Wings and Ailerons.

Under static load the Bristol M.R.1 wing withstood a load factor of 6, when the front spar buckled downwards near to the inner end, causing collapse of the wing and failure of the rear spar also. In a rib test with the centre of pressure forward,

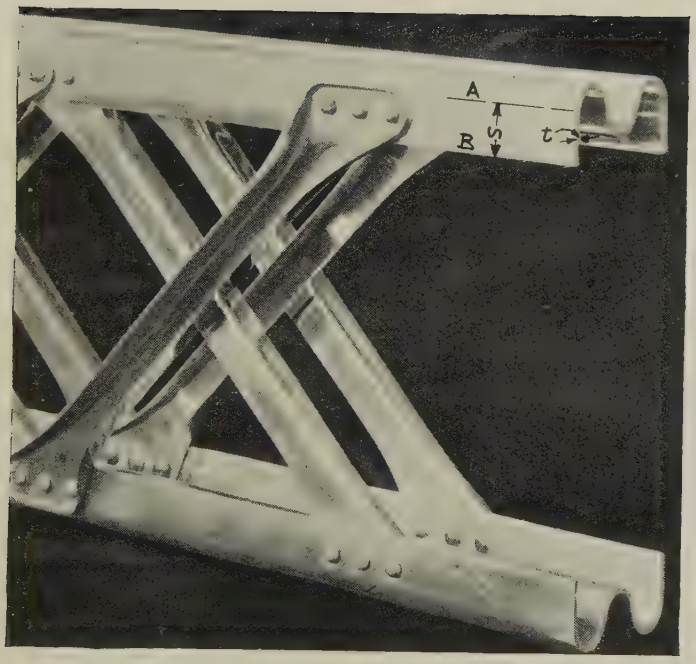


Fig. 35.—Stress in Free Edges of Booms of Spars.

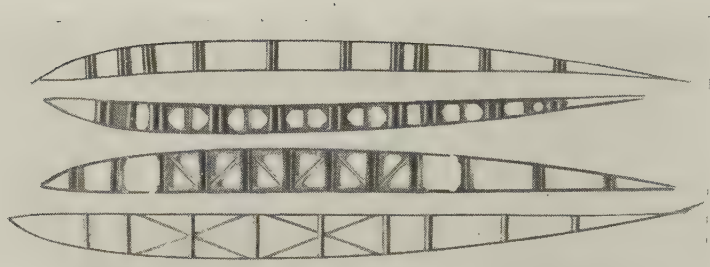


Fig. 37.—Steel Wing Ribs with Channel-Shaped Booms.

Fig. 38. Pressed-Steel Wing Ribs, in Three Portions.

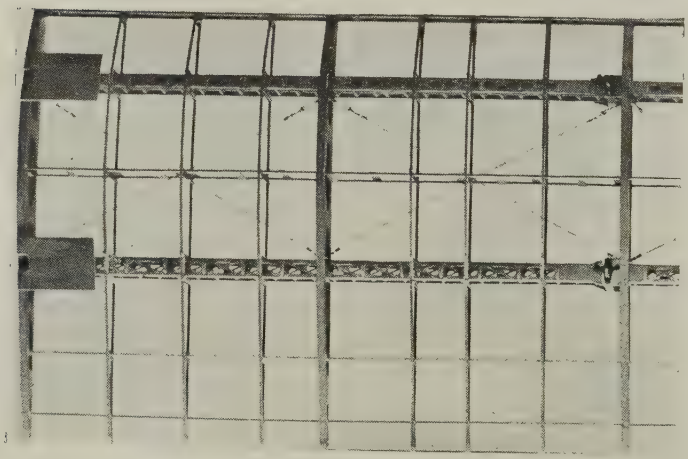


Fig. 39.—Avro Composite Wing with Steel Spars and Wooden Ribs.

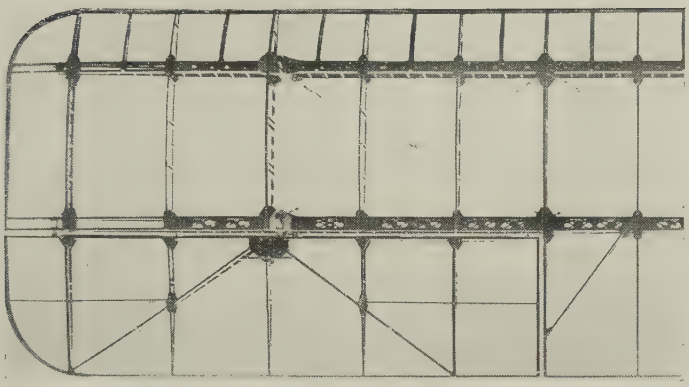


Fig. 40.—Early Type of All-Steel Avro Wing with Aileron.

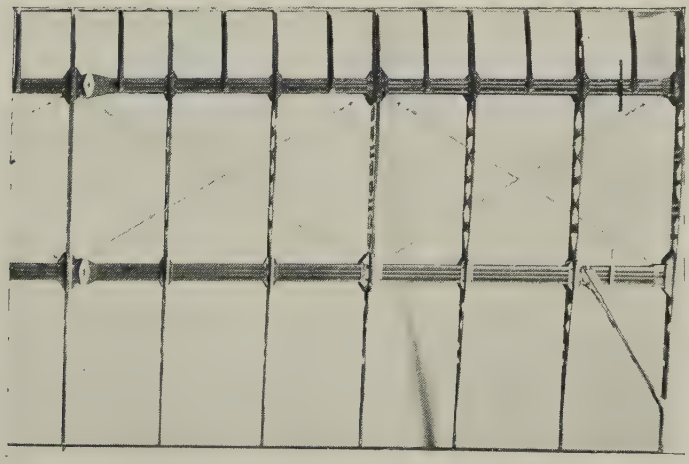


Fig. 41.—All-Steel Avro Wing with Rolled Spars and Pressed Ribs.

Fig. 42.—All-Metal Bristol M.R. 1 Aeroplane.

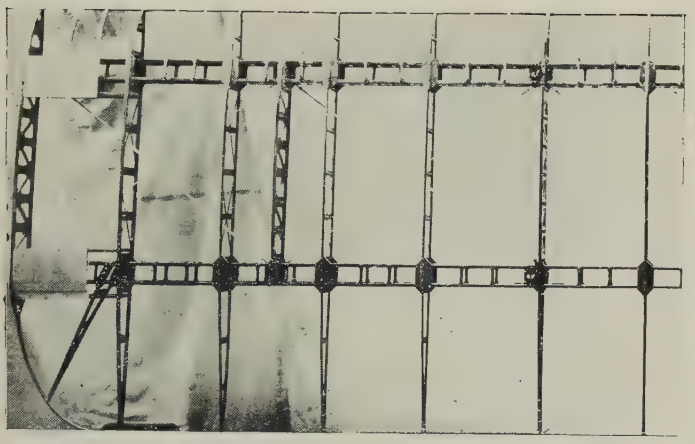


Fig. 43.—Steel Wing for Bristol M.R. 1.

Fig. 46.—Strut Fittings where failure occurred in Duralumin Wings.

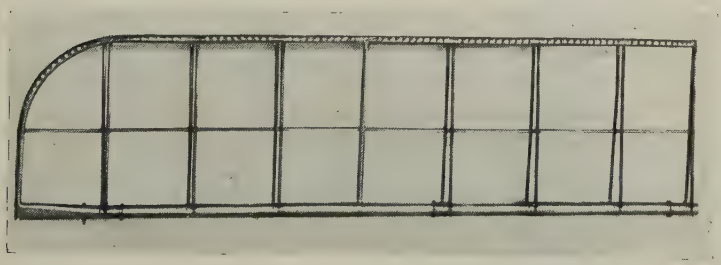


Fig. 47.—Duralumin Aileron on Tube-Joint System

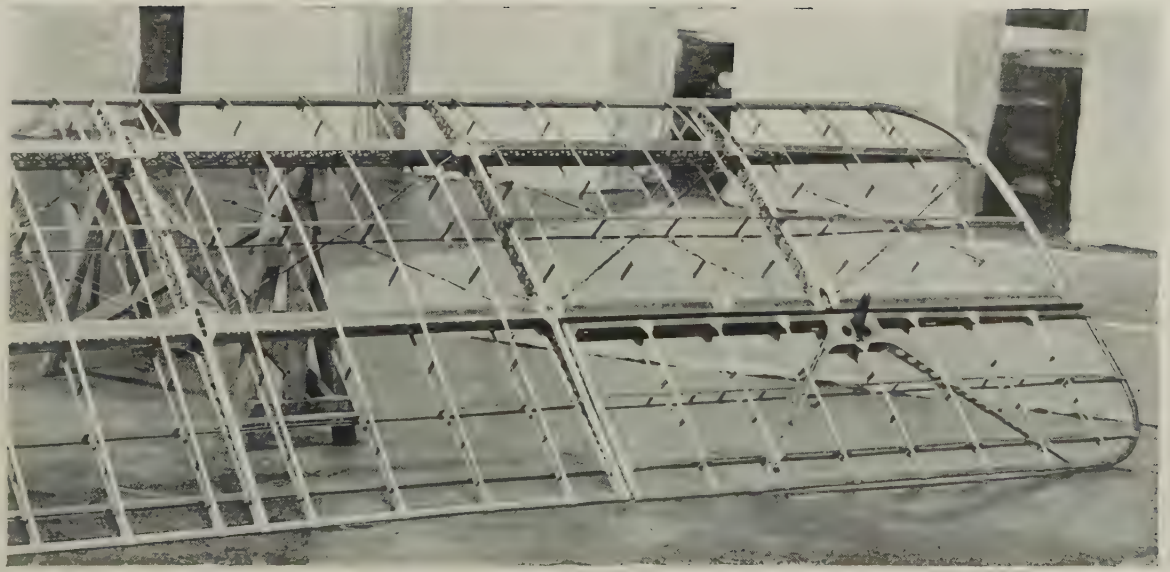


Fig. 44.—Duralumin Wing for Avro 504 K.

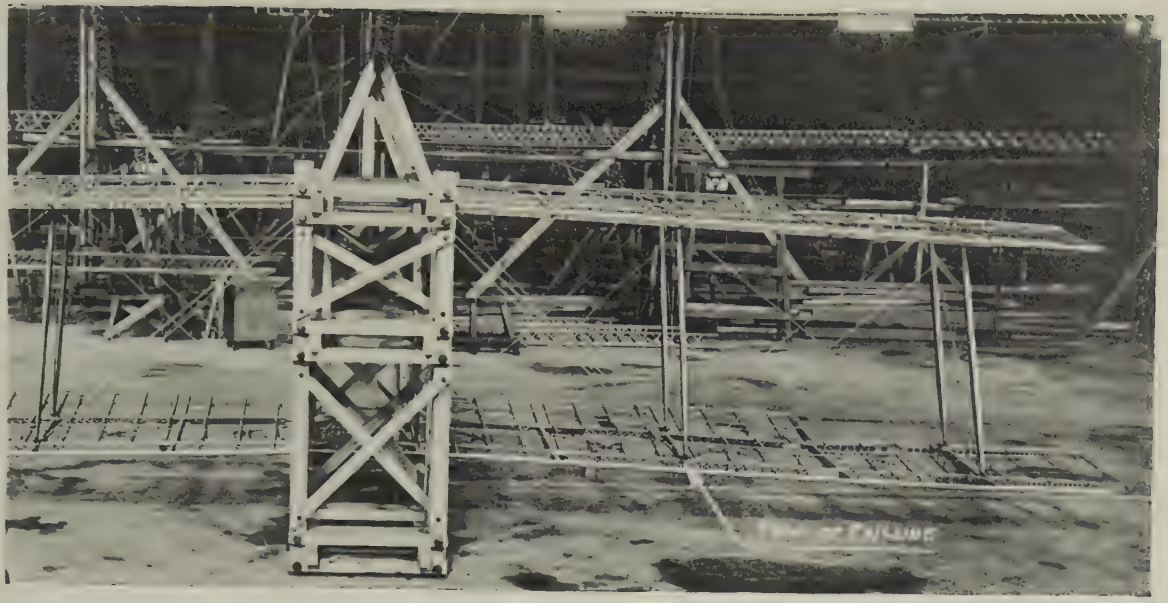


Fig. 45.—Set of Duralumin Wings after Failure in Static Test.

failure occurred at a load factor of 8·2 by shearing in front of the front spar; when tested with the centre of pressure back, failure occurred at a load factor of 6·8 by tension in the diagonal members. The tests showed these wings to be of sufficient strength. Under static load test of the B.E.2d wings with centre of pressure forward, the wing withstood a load factor of 5·82 at failure, against the specified 5. Failure occurred in the compression boom of the front spar just inside the outer strut near to an additional strengthening plate. The ailerons and ribs were also of sufficient strength. The Avro steel wings shown in Fig. 41 were proof loaded to a load factor of 4·2 with the centre of pressure forward, and to 3·7 with the centre of pressure back. On removal of the load in each case the spars, etc., returned to their original position. The deflecton was normal, and there was no lateral bowing. Load factors of 7 and 5 respectively were required before failure occurred. The strength, as indicated by the proof loading, and from the behaviour of similar wings, was considered ample for flight tests.

The Avro steel wing shown in Fig. 40 withstood load factors of 8·7 and 7·94, against the 7 and 5 specified when loaded with the centre of pressure forward and back respectively. In the C.P. forward test an inner lift wire fitting failed, the wing structure being undamaged. In the C.P. back test the loading was stopped by the failure of the neighbouring composite wing; the all-steel wing was undamaged.

The wings may, therefore, be considered to be of ample strength. They are very considerably stronger than the wooden planes, and weighed 55·5 lbs., against the 47 lbs. minimum for the wooden planes.

The ribs developed load factors of 11·9 when tested with C.P. forward, and at a load factor of 15 with C.P. back the test was discontinued.

Composite planes by Messrs. Boulton and Paul, with the steel spars shown in Fig. 13, and with wooden ribs, withstood, without failure, a load factor of 7 with C.P. forward. When tested with

C.P. back, failure occurred by buckling of the webs at a load factor of 6. The planes were, therefore, considerably above strength. They weighed 46·5 lbs., against 47 lbs. minimum for the wooden plane.

Avro Duralumin Wings.

The duralumin wings constructed by Messrs. Vickers & Co. for the Avro machine are shown in Figs. 44 to 46. The main spars have already been illustrated in Fig. 7. It will be seen that the compression ribs are similar to the main spars. The light form of the ribs together with the robust tubular leading-edge should also be noted.

The wings shown in Figs. 45 and 46 were tested at Barrow-in-Furness with C.P. forward, and failure occurred at a load factor of 10·7 by shearing of the rivets securing the gusset plate to the spar at the inner front strut fitting. The strut socket and gusset plate slid along the main spar until stopped by the bolts. On dismantling, it was found that the spar was undamaged. There was no visible lateral distortion of the spars or of the leading-edge.

A large number of static tests were subsequently carried out at Farnborough on similar Avro duralumin wing construction. Very high load factors were consistently obtained, and failure never occurred in the spars. The tests were usually brought to a stop by failure of one of the standard fittings or of the drag bracing. When tested with all the flying and incidence wires in position, load factors of fully 11·2 and 9·8 were reached when tested with C.P. forward and with C.P. back respectively, and when tested with the incidence wiring, and also the wires from the lower plane to the skid removed, load factors of 7·8 and 6·5 respectively were reached when failure occurred at the fittings. When this load factor of 7·8 was reached the distortion of the planes was so great that loading could not be continued. There were several minor distortions in the drag struts, and in one case the riveting sheared on one side of a

cover plate at a butt joint in the main spar, but after these large loads had been removed the main spars and the leading-edge invariably recovered.

The wings weighed 48 lbs., a considerable proportion of this weight being required for the packing blocks due to the standard Avro type of fitting being employed.

An interesting example of a duralumin aileron for the Avro machine is shown in Fig. 47. The aileron is constructed on a special tube joint system by Messrs. M. L. Experimental Co., Dartford, and forms a very light and strong construction.

Flight Tests.

Numerous flight tests have been carried out with the steel B.E.2d and Avro main planes, constructed by Messrs. The Steel Wing Co., without the appearance of any signs of failure from the frequent landings and other severe flight tests to which they have been subjected. The planes have been stripped and carefully examined for failure of the riveting, internal bracing, etc. The only defects observed have been minor, such as the buckling of a number of ribs on the upper sides of the wings near to the trailing edge. A large number of flight tests have also been carried out with success with the Vickers duralumin Avro wings.

Flight tests on the Bristol M.R.1 aeroplane were also satisfactory. The machine finally made a bad landing, one of the lower wings crashing into a tree. A portion of the wing was badly crumpled, but not destroyed, the pilot being uninjured. It is probable that with an ordinary wooden machine the damage would have been much greater.

MATERIALS OF CONSTRUCTION FOR MAIN-PLANE SPARS, RIBS, ETC.

Steel Strip.

The steel strip for the manufacture of wings for the smaller-sized machines is necessarily very thin, being usually from

0·012 inch to 0·022 inch if the weight of the steel structure is to be kept down to that of the standard wooden structure. For the larger types of aeroplanes the steel strip may probably be as thick as 0·056 inch.

The minimum radius of curvature to which the high tensile steel strip need be bent in the manufacture of the main-plane spars is about three times its own thickness, and hence all-steel strip, alloy or plain carbon, should be capable of bending to a radius of three times its thickness in cold rolling to the final form. In general, in the booms of steel spars which develop a maximum fibre stress of 50 to 60 tons per square inch or higher, the usual radius of curvature in the strip ranges from 30 times to 10 times the thickness of the strip.

A consideration of the various spar designs which have been developed indicates the need for at least two qualities of steel strip giving yield stresses of (a) 40 tons per square inch and (b) 60 tons per square inch, the yield stress being specified because this cold-worked material has no definite elastic limit.

The yield stress itself is rather indefinite, and may be defined here broadly as that stress at which the permanent extension of the specimen under tensile test is visible. With high tensile material developing from 60 tons per square inch to 80 tons per square inch the elastic extension is relatively large. For example, at 62·5 tons per square inch the elastic extension on a 4-inch specimen is approximately 0·02 inch, and it is not possible to fix the yield stress without plotting a stress strain curve.

The strip has been supplied either as alloy steel or as plain carbon steel, and both types are eminently suitable for the purpose, giving the required bend tests, and being capable of cold rolling to the required form.

Alloy steel strip of tensile strength greater than 70 tons per square inch has been supplied by Messrs. Kayser Ellison & Co., Sheffield, in their K.E. 897 brand, and for those of lower tensile strengths their K.E. 169 brand is employed.

The composition of these steel strips is on the average

	Carbon.	Chromium.	Nickel.	Vanadium.
K.E. 169 -	0·20	1·0	3·5	0·10
K.E. 897 -	0·35	1·25	3·5	0·10

The steel strip is cold rolled to the finished thickness. It is then heated and hardened by quenching in the coil in water from about 820 degrees C. The strip is then flattened by cold

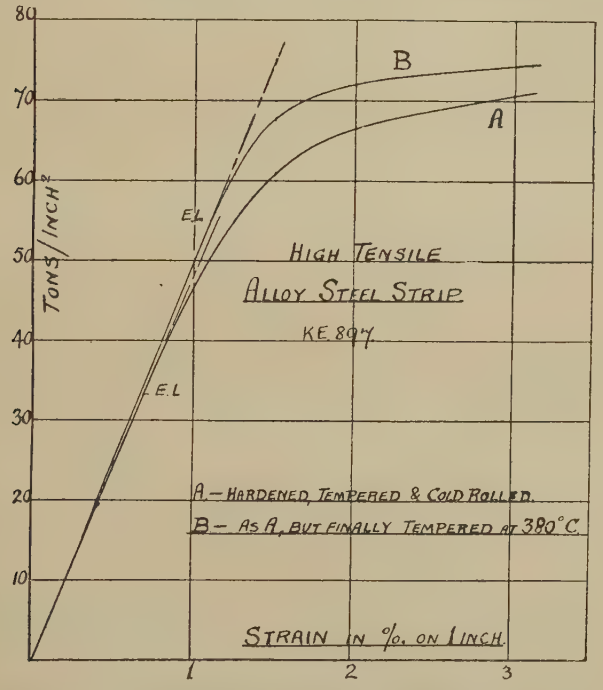


Fig. 48.—Stress-Strain Curve for K.E. 897 Brand Alloy Steel Strip.

rolling, and is finally tempered for about one hour at a temperature of about 400 degrees C. and cooled in air.

This strip when uncoiled and laid out straight does not exceed in curvature $\frac{1}{4}$ inch in ten feet. When tested against the grain the strip will bend round a radius three times its own thickness, through an angle of 180 degrees.

A typical stress-strain curve for K.E. 897 strip is shown in Fig. 48. The influence on the yield stress of tempering for 20 minutes is also shown. The influence of heat treatment, har-

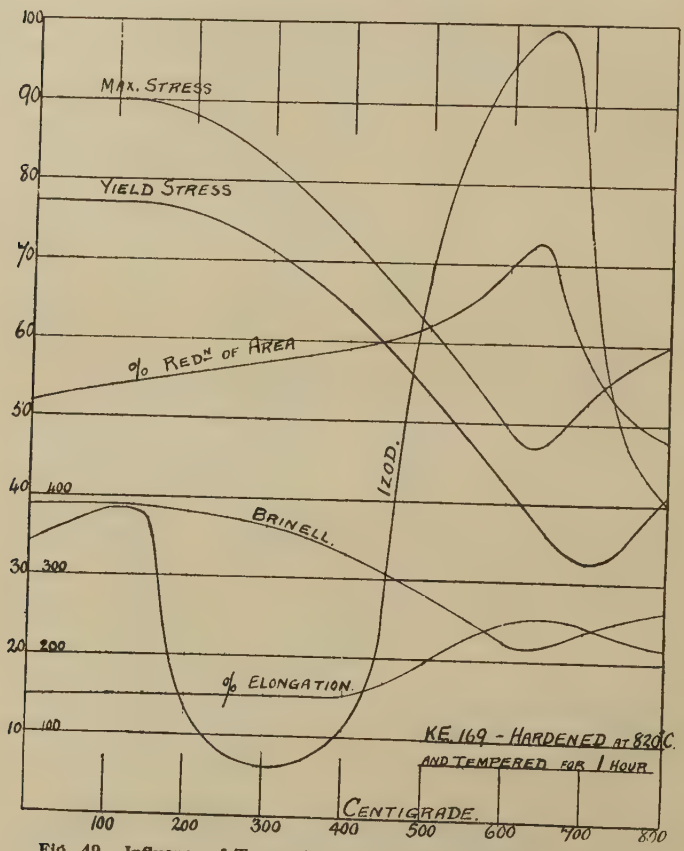


Fig 49.—Influence of Tempering at Various Temperatures on the Physical Properties of K.E. 169 Alloy Steel.

dening in oil from 820 degrees C., and keeping for one hour at various temperatures and cooling in air, on the K.E. 169 brand is also shown for $1\frac{1}{8}$ inch diameter specimens in Fig. 49.

Very similar heat treatment curves will be obtained from the

K.E. 897 brand, and the strip may be tempered down to give a yield stress of 40 tons per square inch, with an ultimate stress of 50 tons per square inch, and an elongation of 12 per cent. on 1 inch with excellent bending qualities.

Plain Carbon Steels.

A large amount of experimental work has been carried out by Messrs A. Lee & Sons Ltd., Sheffield, on the production of plain carbon steel in qualities from 40 tons per square inch to 60 tons per square inch yield stress, with the result that the carbon steel strip has also been found to be suitable for the production of these main-plane spars.

The following information regarding a low carbon steel strip with 0·30 carbon and 0·85 manganese will be interesting:—

Table V.

Condition.	Thickness. Inch.	Reduction of area. Percentage	Yield stress. Tons per sq. inch.	Ultimate stress. Tons per sq. inch.	Elongation percentage on 1 inch.	Bend test over 3 times its thickness.
Close Annealed	·064	—	15·3	18·4	39·5	Good.
Cold rolled to -	·024	62·5	29·0	29·0	2·6	Too hard.
Normalised -	·024	—	33·0	36·5	7·5	Good.
Cold rolled to -	·018	25·0	47·5	53·5	4·0	Good.

Tests were carried out on six different coils, each 450 feet long, of the ·018 inch strip, and the figures quoted in Table V are the average of the test results. These coils were used for the manufacture of steel spars; they were formed to shape without signs of fracture, and the strip was within the required degree of straightness. The normalising of the strip at the ·024 thickness completely restored the ductility lost by the very large previous reduction of area in cold rolling.

A higher carbon steel, normalised and cold rolled in a similar manner gave the following final test results:—

TABLE VI.

Condition of Strip.	Thickness. Inch.	Yield stress. Tons per sq. inch.	Ultimate stress. Tons per sq. inch.	Elongation on 1 inch. Percentage	Bend test over 3 times its own thickness.
Cold rolled to -	·016	60·6	62·2	6·0	Good.
,, ,, ,, -	·018	62·0	64·0	12·0	Good.
,, ,, ,, -	·020	61·5	65·2	10·0	Good.

Coils giving the tests in Table VI were also manufactured into main-plane spars without showing any signs of failure.

The effect of tempering at 350 degrees C. this cold-worked plain carbon steel strip is similar to that shown in Fig. 48 for the alloy steel strip, and would probably result in an increase in the ultimate stress, together with a 5 to 10 tons per square inch increase in the yield stress.

The influence of tempering on the oil-quenched plain carbon steel strip is different to that on the cold-worked plain carbon steel strip, and is rather similar to that shown in Fig. 48 for the alloy steel; an increase in the tempering temperature results in a considerable decrease in the ultimate and yield stress, but with an increased percentage elongation, and also, after the critical temperature between 400 degrees C. and 500 degrees C. is passed, in an improved bending test.

Cold-drawn sections, such as angles, have been produced by Messrs. Bruntons, Musselburgh, and delivered in straight lengths with a yield stress of fully 40 tons per square inch. Such sections when built up with continuous steel strip bracing in the booms and webs should result in satisfactory spars. Hot-rolled alloy steel angles, in sizes down to $\frac{7}{8}$ inch by $\frac{7}{8}$ inch by $\frac{1}{8}$ inch, have also been supplied by Messrs. Brown Bailey, Sheffield.

Duralumin Strip and Sections.

The properties of duralumin which render it eminently suited for aircraft construction are its strength and low specific gravity. Its principal physical properties are:—

Compressive stress, 18 to 20 tons per square inch.
lbs. per cubic inch.
Young's modulus, 4,800 tons per square inch.
Ultimate tensile strength, 26 tons per square inch.
Yield stress in tension, 14·5 tons per square inch.
Compressive stress, 18 to 20 tons per square inch.

These physical properties are dependent on the heat treatment. It is annealed by heating to a temperature between 360 degrees C. and 380 degrees C., and quenching out in water. Under this treatment it becomes plastic, and may be forged or stamped, rolled into sheets, or solid drawn into sections or tubes. The tensile strength does not exceed 16 to 17 tons per square inch with a yield stress of 6 to 7 tons per square inch.

The duralumin is normalised by heating to 500 degrees C. and quenching in water, the physical properties for one hour after the treatment being ultimate stress 22 tons per square inch with a yield stress of 9 tons per square inch, these stresses gradually increasing during the next 10 days to an ultimate stress of 27 tons per square inch with a yield stress of 15 tons per square inch. A correct heat treatment, preferably in a bath of potassium and sodium nitrates, is essential if the properties of the metal are to be developed.

An interesting series of characteristic curves showing the influence of the temperature of treatment on the final properties has been determined by Messrs. Vickers, and is shown in Fig. 49.

If it is impossible or inconvenient to heat-treat after the construction of the parts, the material should be normalised be-

fore the final operation and advantage taken of its relatively soft condition immediately after the heat treatment for the required mechanical operation.

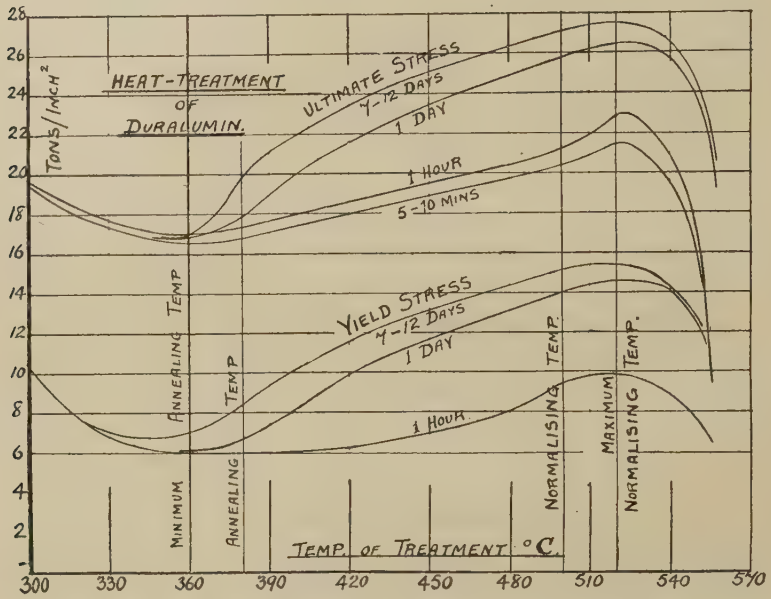


Fig. 50.—Characteristic Curves for the Heat-Treatment of Duralumin.

Protection of Steel Strip Against Corrosion.

The various steel parts on aircraft, and especially these spars and ribs built up from thin steel strip, should be adequately protected against corrosion. It has been found that the most satisfactory process which can be employed is that known as electro-zincing or electro-galvanising. The metal parts should be very carefully cleaned before depositing the zinc, and the coating of zinc should be approximately 0·001 inch thick. An alternative method is to protect the steel by stove enamelling, after the various parts have been carefully cleaned.

In conclusion I desire to express my grateful thanks to General

R. Brooke Popham, C.M.G., R.A.F., for the permission given to read this paper, and to my former colleagues, especially Prof. F. C. Lea, Major H. N. Wylie, R.A.F.; Major J. Goodman, R.A.F.; Major A. Robertson, R.A.F., and Mr. W. D. Douglas for the ready assistance always given in the discussion of the various difficulties as they arose.

My best thanks are also due to all the aircraft firms mentioned for the generous manner in which they have furnished for our benefit the various drawings and photographs of the aeroplane parts, together with the experimental data obtained.

Discussion.

Mr. A. B. Dennistoun (Associate Member): Major Nicholson's paper is a valuable summary of the interesting experimental work carried out during the war in order to find a substitute for wood in aircraft. The results of this research, and the data obtained, together with the theoretical conclusions, are very useful to aircraft constructors. The greater liability to local failure of high tensile steel, and to a lesser extent of duralumin, than wood is clearly shown by the experiments; while, on the other hand, the defects of wood due to natural causes are undoubtedly greater than the defects of metal.

The problem consists of making the strongest and lightest spar within the space available, as the standard wing-section cannot be altered. This is more clearly shown by taking Fig. 21 and drawing the wing rib in position, as in Fig. 51. It will be seen that this spar does not fill up the space very well, as the bulk of the metal is at A, when it would be much more efficient at B, owing to the moment of inertia increasing as the square of the distance of the metal from the neutral axis. For the same reason all spars with angles turned with their free edges to the outside, as in Figs. 30a, 31, and 32, lose in efficiency, and at the same time they usually begin to fail at the free edges, as in Fig. 30a, while further lipping of the free edges causes more complication, and is frequently an addi-

Mr. A. B. Dennistoun.

tional source of weakness. In designs having angles at the corners it would be better practice to turn these, as in Fig. 2a, and experiment to find a suitable bracing.

The great value of duralumin, compared with steel, is proved by experiment, and as it is now being extensively used for aircraft, Major Nicholson might be able to say if any serious trouble has been found to occur, and particularly if any treatment is necessary to prevent corrosion or deterioration under any circumstances where the metal would be used.

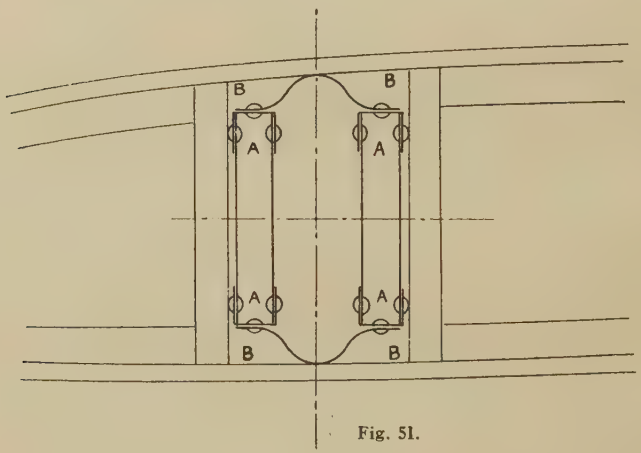


Fig. 51.

Perry's formula for laterally loaded struts given in the paper is an approximate one, but it agrees very well with the tests, as shown by the curves in Fig. 24.

As Euler's formula for struts is only applicable to long struts, it would be interesting if Major Nicholson could state the $\frac{l}{k}$ value below which it could not be used, and to give a formula for shorter struts in duralumin. The following Rankine-Gordon formula has been found to be fairly accurate from tests on channels of duralumin, with hinged ends.

$$P = \frac{35{,}840A}{1 + \frac{1}{4{,}300}\left(\frac{l}{k}\right)^2}.$$

P = Crippling load in lbs.

A = Area of strut in square inches.

l = Length of strut in inches.

k = Radius of gyration of strut in inches.

Mr. Alexander H. Weddell, B.Sc. (Member): I am glad to take this opportunity of congratulating Major Nicholson on his paper, which embodies the result of a great amount of most interesting experimental work. One point that struck me in looking over the large number of sections that have been dealt with is, for the small struts in use on the Avro machine, I see no reason why a solid tubular section should not be practicable. It seems to me that a tube of rectangular section, either with flat faces or with the faces corrugated to increase their stiffness, would form a strut in which the material is disposed in the most economical way, and which would be free from any uncertainties or weakness due to the possibility of premature buckling of imperfectly supported surfaces or edges, which is mentioned on page 230 as a common cause of weakness in built-up sections.

Mr. David S. McLean: Since Major Nicholson delivered his lecture further experiments have been carried out under his direction with very interesting results. High tensile alloy-steel strip pressed into plain flat channel or single arched channel-sections were built up with specially-corrugated high tensile steel-strip webs into beams to form test specimens. Fig. 52 shows a typical beam in position in the testing machine. The beam is supported at the ends by pins through loading-boxes situated on the neutral axis. A state of simple bending is obtained in the middle third of the beam by applying the load at two points 20 inches apart. This central portion of the beam is the part actually under test, and the booms, either flat or curved,

Mr. David S. McLean.

supply the total resistance-moment, the webs, owing to their vertical corrugations taking no part of the bending-moment. The edges of the booms are stiffened by a packing strip at each side, and the webs are riveted through the boom to the packing strip.

Fig. 53 shows end views of the specimens. In order to verify whether the webs took any portion of the bending-moment they were cut vertically through (a) at every fourth corrugation, then (b) at every second, and (c) at every corrugation, and it was found when testing the beam in each case that the deflections agreed to within 1 per cent. Three out of every four corrugations were then cut transversely at the neutral axis, and the same result obtained.

Fig. 54 shows a flat top beam, $2\frac{3}{4}$ inches wide, in the testing machine. On a small load being applied waves appeared in the flat boom, and on increasing the load the beam collapsed at the bottom of one of the waves at an ultimate stress of 19 tons per square inch, as calculated by the formula $f = \frac{M}{Z}$, Z being assumed constant throughout the test. The presence of these waves indicates, however, that the flat central portion of the boom is not taking any of the load, and, in addition, is really causing early failure of the section. The load was taken by corner portions of the boom and by the packing strip. If this is correct the maximum stress developed at the corners is approximately 27·5 tons per square inch instead of the 19 tons per square inch when the whole of the boom is included in the unit. In every case the compression boom buckled in such a way as to reduce its moment of inertia.

The formation of waves in the flat booms at low loads shows that this design, though simple and relatively effective, does not develop sufficiently high stresses. Much better results were obtained from beams of similar design, but with single arched booms.

Mr. W. O. Duncan: Mr. McLean has explained fully the

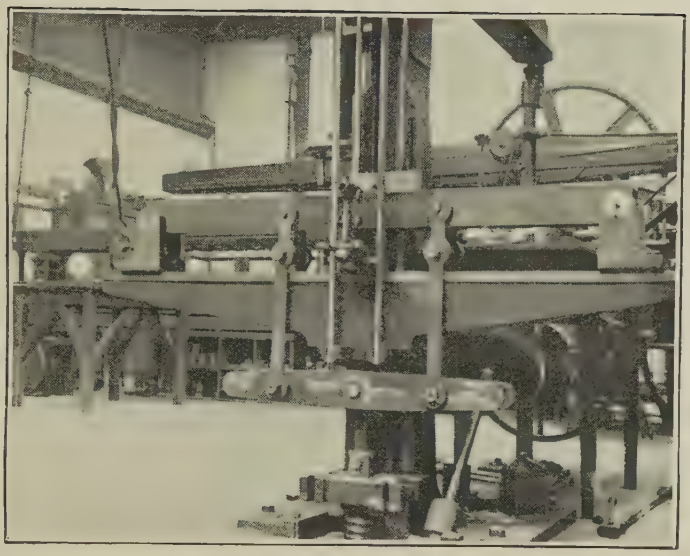


Fig. 52.

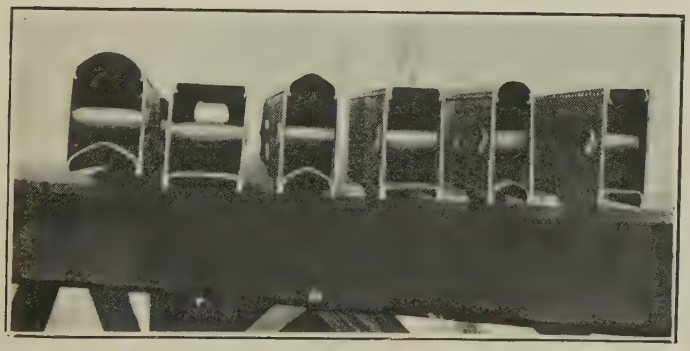


Fig. 53.

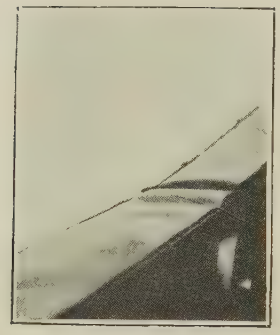


Fig. 54.

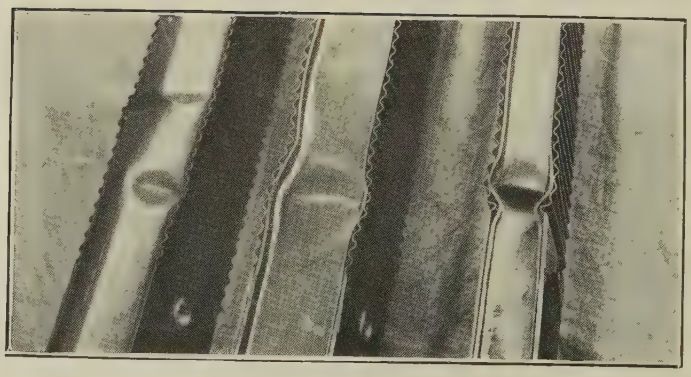


Fig. 55.

Mr. W. O. Duncan.

tests carried out on the beams with flat booms. The tests on those with curved booms were carried out in the same way, and much higher stresses were developed at failure. In three cases the stresses at buckling were 44, 50, and 54 tons per square inch compression respectively in the top boom. These are remarkably high values for such simple sections, especially when compared with the results obtained from earlier complicated designs.

Fig. 55 shows the method of failure of these booms. In every case failure was due to buckling, which started on one of the flat sides of the boom, and then spread to the lips. No waves appeared in the boom before buckling, which would seem to show that the whole of the boom was taking its share of the load. The rolled section of each curved boom is approximately parabolic in form, but with slightly flattened sides. As these flats were the weakest point in each boom, we are of opinion that a rolled section of semi-circular or purely parabolic form would give the best results for a simple section of this type.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Associate Member): I will not presume to say one word about aircraft, but I claim to know something of the design of struts, and also know others who have had to design struts. Each one agrees that it is about the most difficult and unsatisfactory piece of so-called straight designing that he has ever been called upon to undertake. When first I saw this paper I thought, here is some help; but alas! the first little tempting bit of theory seems to me to make confusion worse confounded. After being introduced to the Euler equation, which gives the load when instability sets in, almost immediately following it we are told—an exceedingly true thing—that, in order to improve struts, material must be obtained with a big modulus of elasticity. Following that there is the statement that an increase in the elastic limit is equally important. Now, if the failure of a strut is due to the sort of instability that is investigated in

Mr. W. H. Riddlesworth, M.Sc., M.Eng.
what is generally spoken of as the Euler equation, I fail to see where the elastic limit comes in in any way. Possibly Major Nicholson will put me on the track, and I can assure him that anything that will help to elucidate the mystery of the strut will be very welcome. So much for the paper.

Some diagrams have just been shown giving the results of testing certain beams which, as I gather from the description of the test, had a uniform bending-moment over the portion that was being considered; in these the web or members connecting the upper or lower booms were corrugated strips. It seems to have been cause for surprise that no difference in the deflection was found when these corrugations were cut through. I do not think there is any reason for surprise, as in that portion of the beam there are no shearing forces; these are the forces the web generally takes care of, and all the web has to do is to keep the two portions (the upper and the lower booms) apart. As long as the short sections of corrugated web perform that function they do all that is asked of them at the time, and possibly had the web been removed altogether, and a series of little bits of lead pencil put in to keep the two members apart, the result would have been very much the same.

For an example of a beam without a web in ship construction, see the paper on "The Duct Keel" by Mr. Spanner, read last session.

Mr. Gordon Elvidge: Major Nicholson's paper contains a considerable amount of information which will be helpful to anyone really interested in the subject. I should like to have seen some reference in the paper to the manufacturing costs of these spars, when compared with those of wood, and with this in mind it appears to me that before metal spars become really popular, and more or less universal, an alteration will have to be made in the present method of manufacture. This is not constructive criticism, but just now I do not see how to make a cheap metal spar which at the same time will be light enough. The most difficult operation with the spars which are

being made by Messrs. Bruntons at Musselburgh is the drilling of the thin springy steel of curved section. I think it will certainly be a great help to have something stiff and flat, such as drawn angles to form a skeleton when building up a long spar on a jig.

Mr. H. B. Pratt: The peculiar behaviour of duralumin in gradually hardening up after treatment gave rise—when the metal was first introduced—to certain natural misgivings as to the permanence and stability of the material in the hardened condition. These have, however, proved unfounded. Tests in 1918 on some of the material which had been exposed in the open since 1910 showed the same strength as obtained within a week after treatment. It may be noted also that these same specimens showed only a very slight surface discolouration due to the presence of oxide, although exposed in the open air for this period alongside a dock where the air is naturally very moist.

Duralumin is also almost unaffected by exposure to sea water and air, as was demonstrated by the following experiments:— Four plates, 1 inch square, were exposed for a full 12 months, viz., from January, 1913, to January, 1914, to the action of sea water and sea air alternately in the Walney Channel at Barrow. The plates were fixed to a suitable anchorage at such a position in the Channel that they were at about mean water-level, so that they were exposed for about equal periods to the sea water and sea air in accordance with the tides. The four plates represented different qualities of duralumin, but only one quality, *i.e.*, B. Normal, is now used in duralumin construction, and the results of the corrosive action on the plate of this type are as follows:—

Weight of plate before immersion - -	412·39 grammes.
Weight of plate after immersion for 12 months	411·75 grammes.
Loss of weight in 12 months - - -	·54 grammes.
Percentage loss - - - - -	·13.

Mr. H. B. Pratt.

As two square feet of surface were exposed to the corrosive action, the loss per square foot, of course, is one-half the total loss shown. The loss in the 12 months of weight of the plates is less than ·13 per cent. of the total weight. The plates were of material as delivered from the rolling mills, and no varnish or protection of any sort was on the surfaces. It cannot, of course, be claimed that duralumin is unaffected by exposure to sea water, but it is far ahead in this respect to any other light alloys, and is certainly much superior to steel plate in the natural condition. It is recommended that duralumin submitted to sea water or sea air should be covered with a varnish, and in cases where the weight can be allowed, should be covered with a good protective coating.

Heat has an influence on the resistance of duralumin. According to the results of tests of heated material the strength whilst hot decreases 10 per cent. on heating to 100 degrees C., and to about 20 per cent. at 150 degrees C., and decreases with increased temperature. The elongation scarcely increases with increased temperature, and between 150 degrees C. and 200 degrees C. it decreases. At 250 degrees C. the elongation at normal temperature is reached, and if heating is prolonged the elongation increases with higher temperature. From this it will be seen that whenever duralumin is used for parts that are exposed to heat the possible decrease in strength must be taken into consideration. The properties of duralumin are not so much influenced by cold. The results of tests carried out down to a temperature of −200 degrees C. show that both tensile strength and elongation increase slightly with increasing cold.

Copper, brass, and bronze are electro-negative relative to duralumin, and should never be in metallic contact where exposed to moist air. Steel, however, is electro-positive to duralumin, and does not cause any corrosion to the latter when joined to it, and subject to moist air. Duralumin and steel bars riveted together have been totally immersed in sea water for a period of 12 months. The result was a small corrosion

of the steel and a total loss of weight of the duralumin of ·23 per cent. There is, therefore, no objection whatever to the use of steel and duralumin in metallic contact, but the steel, of course, should be prevented from rusting by enamelling or painting. Galvanising should not be used.

Duralumin depends entirely on heat treatment for its remarkable physical properties. Particulars of the method and temperatures of treatment have been given in Major Nicholson's paper. Correct heat treatment is essential if the best properties of the metal are to be developed to their fullest extent. Unlike the corresponding treatments of steel, the temperatures necessary are relatively low and easily controllable. If only a simple one-operation bond or pressing is to be done, the material need only be treated at the normalising temperature, 480 degrees C. to 500 degrees C., and the work done within one hour of treatment whilst the material is in the temporary soft condition. No further treatment is then required, as the material will return to full strength in 24 hours.

Simple bending on very thin material can usually be done in the finished condition without any treatment. If, however, several operations are required to be done, the material should either be treated at the normalising temperature before each operation, and the work done within one hour of each treatment, or, what is preferable and safer, where the material is subject to severe work, it should be treated at the annealing temperature, when it may be safely worked as many times as necessary within four days of treatment. But if the working is exceptionally severe, it may be preferable to anneal between each operation.

Major H. N. Wylie, R.A.F.: To many engineers the structures described in the paper may appear to have little application outside of aircraft. Nevertheless, with the rising price of material, and with labour's growing preference for ever "lighter and lighter work," the time may come when some of the forms shown in the paper, made, of course, of some kind of uncorrod-

able metal, are used for long span bridges and other engineering works. Whatever its application, however, the subject is a considerable extension to the theory of structures, and is so new, and of such interest, that I venture to elaborate one or two points which seem to me to call for special emphasis. In mild steel structures built of ordinary thick sections, failure does not occur until the yield or even the ultimate strength of the material is exceeded. In light metal structures, on the other hand, failure is usually due to compression stress, which stress usually has a value between the elastic limit and yield of the material.

In high tensile material the elastic limit and yield are frequently wide apart; an elastic limit at 15 tons per square inch and a yield at 90 tons per square inch were formerly not uncommon in aeroplane axle tubes and in alloy steel strip. In consequence of this, high tensile strip is not now specified by yield but by " effective strength," which is the stress at which there is a permanent set of one-tenth per cent. of the length. This set is one-fifth of the set at the yield as defined in standard specifications. The specification for high-tensile alloy-steel strip requires an " effective strength " of not less than 70 tons per square inch, and the stress-strain diagram of a strip just meeting this is shown by curve B in Fig. 48 of the paper. The manufacture of high tensile steel suitable for this work is a new thing, and none of the tests described in the paper were made on spars of such suitable steel as is now available, for even when steel having a tensile strength of 100 tons or over was used, its elastic limit and effective strength were usually low.

Duralumin in the normal or heat treated state has an elastic limit of about 10 tons per square inch, an effective strength, as above defined, of 14 to 16 tons per square inch, and a yield point which is required by the standard specification to be not less than 16 tons per square inch, and is usually 18 tons per square inch. The failing stress in compression is shown in Fig. 36 of the paper as increasing from 11 tons to 16 tons per

square inch as the stability of the section is increased, and the failing stress in the spars made by Vickers for the Handley-Page and Vimy machines rose from about 14 tons in the lightest to 17 tons per square inch in the heaviest sections. I think, therefore, that 16 tons per square inch is a fair figure to take for the effective strength of duralumin in comparing it with steel. On this basis standard high-tensile alloy-steel is 50 per cent. stronger than duralumin of equal weight, and standard high-tensile carbon-steel, which has a minimum effective strength of 55 tons per square inch, is 20 per cent. stronger than duralumin of equal weight. Duralumin, moreover, has not given such satisfactory results in flying tests as steel. It is, in fact, suspected of a tendency to develop fractures, and it is evident that it must be carefully used. I have emphasised the above comparison, because it seemed to me that anyone reading the paper hurriedly, and not acquainted with the subject, might conclude that duralumin has predominating advantages over steel for aeroplane spars, and such a conclusion would, I think, be altogether wrong. I have still, however, to deal with Major Nicholson's point that "a design which is good enough and safe enough in duralumin may be impossible in steel." The designs that illustrate this best are those shown in Figs. 33 and 34, which are the lighter spars for the largest Handley-Page machine. The duralumin spar shown in Fig. 33 weighs 2·4 lbs. per foot, and after supporting more than the specified load it failed by waves forming in the flat back of the channel, final collapse occurring at a stress of 16·7 tons per square inch. If this spar were made of identical form and size and thickness, in steel having a sufficiently high elastic limit, it would fail at a stress of about 56 tons per square inch. It would, however, weigh 6·7 lbs. per foot, which is 2·8 times too much. To bring back the weight to 2·4 lbs. the depth, breadth, and thickness might each be divided by $\sqrt{2{\cdot}8}$. This would not affect the stability, but would reduce the moment of inertia of the section so much that the spar would not be strong enough. If, on the

other hand, the thickness only were reduced, by dividing it by 2·8 the failing stress would be reduced to about 7 tons per square inch owing to the reduced stability of section, so that the spar would have only about one-fifth of the necessary strength. This illustrates Major Nicholson's statement quoted above, and brings into prominence the problem of stability of section which is the central problem in light construction. Turning now to more stable sections, the Rudge section shown in Fig. 9, although it failed at a stress of 64·6 tons in the test described in the paper, failed because the steel in the webs was too soft and not because 64·6 tons was the limit of stability of the section. An earlier sample had, indeed, developed 74 tons per square inch before failure, although it was of thinner steel and weighed only ·52 lbs. per foot, and samples afterwards made of steel having an effective strength of 70 tons per square inch or over developed over 80 tons per square inch before failure, showing that the stability of the section was very high. One specimen indeed failed, not in the compression, but in the tension boom.

Now it is known that the stability of a section does not depend on the scale to which it is made, provided that all dimensions, including thickness, are maintained in the same proportion. If, therefore, the depth, breadth, and thickness, etc., of this section be each increased in the ratio of 2·4 to 1, the stability will be unaffected. This will result in a spar that is 6 inches deep, weighing 3 lbs. per foot, and which is much stronger than the duralumin spar, or than is necessary. To meet the difficulty of weight the section shown and another section, also 2½ inches deep, but of slightly different design, were made and tested in steel of various thicknesses down to ·004 inch, which last has a ratio of thickness to depth much less than is likely to be required in actual construction, even for the largest machines. By suitably enlarging the scale of one of these experimental test specimens in the manner described above, a spar is obtained 7 inches deep and weighing 2 lbs. per foot, and sufficiently stable to de-

velop the effective strength of 70-ton steel. This spar is at least as strong as the duralumin spar which is 20 per cent. heavier. If, instead of being made lighter than the duralumin spars, each of the steel spars were made to have the same weight as the corresponding duralumin spar, each would be stressed by the loading that caused the duralumin spar to fail, to about 45 tons per square inch, and, if made in steel having an effective strength of 70 tons per square inch, each would have a reserve of strength of 25 tons per square inch, which would be useful in the case of a crash. A steel spar $7\frac{1}{4}$ inches deep by 5 inches wide, weighing about 2·4 lbs. per foot, was recently tested, and had practically the same strength as the duralumin spar shown in Fig. 33. It was made up of Dunlop sections taken from stock which were of soft steel having an elastic limit of about 25 tons per square inch.

I wish again to refer to the Rudge Avro spar, one test upon which is described in the paper. The steel in this spar had a value of E = 12,900. The shear deflection under the conditions of test reduced the E of the spar to 12,610 tons per square inch. The spar was elastic almost up to failure when the yield of the steel in the webs' edges was reached, and just before failure the spar took a set of $3\frac{1}{2}$ per cent. of the deflection, so that the apparent E at failure was 12,140 tons per square inch. Spars having properly designed webs, and made of properly heat-treated steel of any of the qualities that are now standard, should generally have an apparent E at failure of about 12,000 tons per square inch. The value of 9,000 tons per square inch given by Major Nicholson in connection with Fig. 2b is, therefore, exceptional. In the preparation of Fig. 25 it has been assumed that in a given spar of given overall dimensions, the thickness may be reduced so as to reduce the weight without the failing stress being effected. This is certainly not in accordance with what is known of stability of section. Stability, in fact, varies as some power of the thickness between 1 and 2, depending on the feature to which unstability is due. Consider,

for example, the spar shown in Fig. 18 which failed at a little under 40 tons per square inch, which was just above the elastic limit. This spar has evidently a "modulus of stability" very little greater than 40 tons per square inch. Assume it is 42 tons per square inch, and that it varies as thickness to the power 1, then reducing the thickness by 24 per cent. to bring the weight to standard reduces the failing stress to 32·8 tons per square inch. The apparent E of this spar at failure was, moreover, 10,800 tons per square inch, so its failure would not lie on the E = 9,000 curve.

The Rudge Avro spar shown in Fig. 9 is stated in the paper to have failed at a load factor of 8. Actually this spar was tested under a different combination of thrust and bending from that finally adopted, and the load factor was not obtained directly as in other tests, but by calculation. The calculation was made, presumably, by the formula which Major Nicholson, in reference to Fig. 24a, explains may be 13 per cent. out, because the result in this case is 8 per cent. out, and the actual load factor is 8·6. In Fig. 23 shear deflection curves are given showing the superiority of a plate web over other webs. The plate web of this test, however, had practically failed at a shear stress of 5·2 tons per square inch, and the deflection at this stress was ·073 inch on a 12-inch length. This is a very poor performance for a plate web, and does not represent the results that should be obtained. Rudge webs of the same thickness have withstood a shear stress of 20 tons per square inch without failure, and with a deflection of one-fifth of the above at the same stress.

I do not quite agree that the designer of spars should aim at getting the highest possible moment of inertia in order to get the highest possible load factor. Steel spars for the Handley-Page machine, if designed to be even 6 inches deep, are lighter and stronger in steel with $k = 2{\cdot}25$ than in duralumin with $k = 3{\cdot}25$. This is, of course, partly due to steel being stronger than duralumin, and partly due to the webs

being continuous, thus reducing shear deflection and taking a considerable part of the thrust. In the Avro tests, certainly, the moment of inertia had a very marked effect on the load factor, but the Avro spars are exceptional and unrepresentative, as is clearly shown in the paper in connection with Table III. In any case it is not certain that a load factor in a laboratory test greatly in excess of what is called for is the best measure of merit. Consider, for example, the spars shown in Figs. 9 and 18, when each is loaded to the specified load factor of 6, which represents the load due to six times the deadweight of the machine with all aboard. Spar 9 is stressed to 36 tons per square inch, which is 28 tons less than the breaking stress, and spar 18 is stressed to 22 tons, which is 18 tons less than the breaking stress. From this it follows that spar 9 can bend much more than spar 18 before it breaks. Now it is quite certain that end loads greater than those corresponding to a load factor 6 can never come on the spars, because the standard fittings which impose end load are not strong enough. They are hardly strong enough, in fact, for a load factor of 6, although they have been found amply strong in service. I think, therefore, that, particularly in a redundant structure such as an aeroplane wing, the spar that, when it is supporting the specified maximum loads, has the greatest reserve of flexibility, is a safer spar than one which has a less reserve of flexibility, but, being stiffer, may be able to withstand a greater end thrust and hence have a greater load factor in a laboratory test.

Mr. Bernard A. Duncan: This paper is of particular interest to one who has been connected with the experiments described, but it is to be regretted that no opinion is expressed on the essential research ahead; for instance, on the treatment of material to prevent corrosion, or why those engaged on research in metal construction are only copying one type which has been found satisfactory for timber structures, especially when a preliminary investigation into the design of cantilever wings immediately shows the superiority gained by using metal. I

Mr. Bernard A. Duncan.

wish the conclusion, on page 219, in comparing the duralumin and steel Avro spar specimens, could be driven home. Major Nicholson infers that duralumin is the material of construction of the future, and from the point of view of strength with lightness, and ease of construction, I agree, but can Major Nicholson not say that the prejudice against its use in this country is unfounded? Junkers' machines have been flying for years exposed to the weather for long periods, but have not yet crumpled to powder, in spite of steel and duralumin parts being riveted together in some cases.

With Major Nicholson's conclusions in general, by the analysis of the test results, I agree, but his method seems weak. Everything is based on an imaginary fibre stress at failure, found by using formulæ which assume elastic conditions and a definite distribution. That this assumption is far from correct can be best illustrated by way of an example as follows—Plot points on Fig. 25 corresponding to the cycle rim specimen, 0·64 lbs. per foot, and that of the Steel Wing Co.'s, 0·72 lbs. per foot for a load factor per unit weight of 7, the corresponding actual load factors being 7·72 and 8·7 respectively. It will be seen by reference to Fig. 24 that under these conditions both specimens are to all intents and purposes only elastically strained, the small discrepancy from the ideal characteristics S_2 and S_3 being due to the greater deflections in testing as explained on pages 213 and 214, yet on Fig. 25 the point just plotted for the cycle rim specimen is above curve L, and that for the steel wing specimen below curve S, which means, according to the interpretation on page 216, that the stress in the latter case, 35 tons per square inch, is *very* usefully developed, but in the other, 48 tons per square inch, it is higher than need be, whereas actually both are ideal performances.

Major J. S. Nicholson, O.B.E.: Mr. Dennistoun referred to the advisability of winged spars built up with angles at the corners, and the angles turned inwards as in Fig. 2a, instead of outwards, as in Fig. 30a. It is clear that the first method, with

the angles turned inwards, gives the best lateral moment of inertia, but this method of construction is at all times difficult to rivet, and if there are continuous corrugated members in the booms and the webs, it becomes almost impossible to complete the riveting. For this reason, in certain of the test designs, the angles were turned outwards, allowing one to get at all the surfaces, building up first the webs and completing the spar by riveting the boom bracing. A comparison, however, of the manner of failure, shown in Figs. 2a and 2b, with that in Fig. 30a, does not show that the construction in Figs. 2a and 2b is less liable to failure at the free edges of the angles than that in Fig. 30a. There is no reason why one type should be better than the other in that respect. The Singer design, shown in Figs. 21 and 51, was chosen to illustrate a spar specimen with an arched boom, in conjunction with channel corner members. It was hoped that this construction would give better results than if the channels were placed at the extreme corner spaces marked B in Fig. 51. It had been proved repeatedly in all specimens with steel channels that the design was not satisfactory. The lips of the channels failed locally, and consequently it was thought advisable to test a design with a strongly-arched boom riveted to the channels, as in Figs. 21 or 51, thus stressing the free lips of the channels at A only to a fraction of the stress in the arched boom at B. The design was moderately successful.

Referring to corrosion, I understand the consensus of opinion is that there is no danger of the corrosion of duralumin. The stability, or the permanence of the material, depends on the heat treatment. The heat treatment should be carefully carried out, and in this connection I would refer those interested to the communication from Mr. Pratt, whose firm (Messrs. Vickers & Co.) have had a very large experience of duralumin, both for the rigid airship and for aeroplanes and seaplanes. So far as non-corrodibility is concerned, duralumin is certainly very preferable to steel.

Major J. S. Nicholson, O.B.E.

I am interested to learn that Mr. Dennistoun has found the Rankine-Gordon formula to give good results on duralumin channels with hinged ends. This formula is not a rational one; it is correct for very long struts and also for short struts where $\frac{l}{k}$ is small, but is not necessarily correct for intermediate values of $\frac{l}{k}$. This formula is more generally known than the rational type containing the secant term which is introduced by assuming definite eccentricity of end loading. The latter type is more elaborate, and probably at the present stage of metal construction, when experiment and practice are so closely associated, the Rankine-Gordon formula will give, with a proper choice of constants, satisfactory agreement with experiment if proper care is taken to apply the end loading through the centroid of the test specimens.

Mr. Weddell is of opinion that a rectangular tubular-section with plain or corrugated faces should be practicable; such a plain tube in duralumin is, weight for weight, amply strong enough for the Avro 504 K aeroplane, and has been largely employed for the main plane spars of the French Breguet machines. This construction or one with corrugated faces, is fairly simple in duralumin, but, even in duralumin, might not be light enough when the main plane spars are from 6 inches to 8 inches deep or greater. In steel a plain rectangular tube would be suitable only for the smaller spars, and corrugations would not be easily introduced into the booms and webs. For interplane struts the most economical sections have been oval, with a suitable trailing edge.

The further experiments briefly described by Mr. McLean and Mr. W. O. Duncan indicate the relatively high stresses which can be developed in steel spar specimens with flat booms and single-arched booms. Fig. 54 indicates the corrugations on a flat boom $2\frac{3}{4}$ inches by ·019 inch thick, the ultimate stress being fully 19 tons per square inch, and with similar booms

2 inches and $1\frac{1}{2}$ inches wide, the ultimate stresses were 28 and 32 tons per square inch respectively.

Mr. Riddlesworth refers to the Euler equation and to the difficulties inherent in the designs of struts. In the spars built up from tubular, angle, and channel sections, numerous experiments on such sections have shown that under compression the failing loads with free ends agree very closely with the Euler crippling load in cases when $\frac{l}{k}$ is greater than 60, if the failure of the member was primary and not secondary; hence my frequent reference to the Euler crippling load. In the case of shorter struts with the ratio of $\frac{l}{k}$ equal to or less than 60, the failing stress naturaly approximates to the yield stress or to the elastic limit of the material; hence my reference to the importance of obtaining a high elastic limit and yield stress by heat treatment or otherwise. The higher the elastic limit of the material the more closely will the failing load agree with the Euler crippling load at the lower values of $\frac{l}{k}$. Every possible use was made of the numerous tests carried out on strut specimens in the design of the built-up spars. The experimental test results were naturally plotted on a base of $\frac{l}{k}$, and compared first with the Euler crippling load and, as mentioned above, reference to more elaborate strut equations was deliberately avoided.

In connection with the experiments referred to by Mr. McLean and Mr. W. O. Duncan, Mr. Riddlesworth states there is no reason for surprise that the presence (or absence) of the corrugated webs should not affect the deflection of the beams. I quite agree, especially after the experiments have shown that to be the case. Unfortunately, however, the result was not so apparent at first, and had nothing to do with the absence of shearing forces. The webs of a beam resist bending-moment just as the booms do. In this particular example the moment of inertia of the web was one-third of the moment of inertia

Major J. S. Nicholson, O.B.E.
of the boom, and thus by including the web an error of 25 per cent. could be made in the moment of inertia of the section, and an equal error in the calculated stress at any part of the section. Consequently, in order to find out whether the corrugated webs really were adding their quota to the strength in bending, tests had to be made, and this was done by cutting the web transversely, first at 2 inches pitch, then at 1 inch, again at ½ inch pitch, and finally by slitting it longitudinally at the neutral axis. In each case the same loading gave equal deflections, proving that this web did not add directly anything to the strength of the beam. Such transversely corrugated webs were employed for that reason. Tests were to be carried out on the strength of the booms alone, and, naturally, one desired the webs to be as neutral as possible.

Mr. Elvidge states that in his opinion angles at the corners of a spar section would be an advantage, and with that I agree generally. At present, however, there does not seem to be enough information on the subject. The cost of the main plane spars in metal will probably be greater than in wood, but I understand that towards the end of the war "Rudge" spars for the Avro 504 K machine were offered at about £5 each for small quantities—a price which compared favourably with that of wooden spars, especially if the cost of the rejected timber spars was taken into account.

Major Wylie was one of the chief protagonists on the all-steel machine, and probably has done as much on the development of the all-steel machine as anyone else in the country. His wide training in structural steel work in the Glasgow district put him in an excellent position to undertake this development work. Major Wylie is a strong advocate of high tensile material for these aeroplane structures, and apparently advises the use of 100 tons per square inch steel, and states that one or two of the designs mentioned can take full advantage of such material. These designs are stable and will develop a maximum stress of 100 tons per square

inch before failure by buckling. Special mention is made of the Rudge type of section, one of his own particular designs, and with his remarks concerning the Rudge design I cordially agree. I consider it one of the very best of the steel designs. It proved stable up to very high stresses in the past, and Major Wylie states that the design has recently given even more satisfactory results.

With regard to this high-tensile steel strip he states that it must not be specified by the yield stress but by the "effective strength" of the material, and he defines the "effective strength" as that stress at which the permanent extension is one-tenth of 1 per cent. It will be realised how extremely difficult it is to guarantee that the effective strength of a certain material is, say, 60 tons, when to do so one has to measure a permanent extension of one-tenth of 1 per cent. I am rather at a loss to understand how the ordinary tester, who notes the yield stress of a specimen by the aid of a pair of dividers, will be able to guarantee this "effective strength." In any argument as to strength I think one ought to keep at the back of his mind the fact that it is not strength alone that is required. It is strength, plus stability, and certainly on paper high-tensile steel appears to be very much better than duralumin, but by the time one gets down to actual construction it is found that duralumin designs are so much more stable than those in steel that the real results do not agree too closely with the paper calculations. For that reason I have been rather in favour of the duralumin design. There have been one or two remarks made about the permanency of duralumin, and so far I have never heard of the failure of duralumin structures, with the exception of the failure under vibration of certain riveted joints where the size of the rivets was very small. On the other hand, the German Junkers' aeroplanes mentioned by Mr. B. A. Duncan have apparently, so far as is known, been satisfactory in that connection. There, however, a big part of the riveting is with steel rivets, which

Major J. S. Nicholson, O.B.E.
seem to be quite satisfactory after a considerable lapse of time.

I am pleased to learn from Major Wylie that a built-up spar specimen $7\frac{1}{4}$ inches deep by 5 inches wide, with, I believe, Dunlop type sections at the corners, and of material with an elastic limit of only 25 tons per square inch, had a strength equivalent to that of the duralumin spar in Fig. 33. The information given on the shear stress developed in the Rudge web is valuable, and I agree that the superiority of the corrugated plate web over the lattice web is much better than is indicated by Fig. 23. In Fig. 25 the upper locus of the various experimental points from all types of Avro spar specimens is given by the E = 9,000 tons per square inch curve, but if, as Major Wylie states, all the specimens had been properly built, with suitable webs and of properly heat-treated high-tensile material, then the various experimental points such as T_2 should lie very close to the S curve whose E = 13,000 tons per square inch, and give at failure an apparent E of, say, 12,000 tons per square inch.

With regard to Major Wylie's remarks concerning the moment of inertia I of the section I agree generally. So long as the stability of the section is not materially affected thereby, the moment of inertia should be increased as much as possible. One fact very apparent from the experiments on duralumin is the simplicity of the sections and the absence of any special corrugations; many of the earlier Avro steel spar specimens were corrugated too highly. A consideration of the results of the experiments detailed by Messrs. McLean and W. O. Duncan strengthens my opinion on the advisability of keeping all sections as simple as possible. The opinion expressed in the closing sentence of Major Wylie's communication should be carefully considered.

Mr. B. A. Duncan mentions that the design in metal has followed that of the wooden machine. That is true, because during the war all-metal parts had to be interchangeable with the

Major J. S. Nicholson, O.B.E.

corresponding wooden parts, but I quite agree that the future of the metal machine may lie in a development radically different from that of the wooden machines, and designers have got in that direction an excellent lead from the Germans in the Junkers' machines, in which the main-plane design is of a tubular, lattice, cantilever type, strengthened transversely by the corrugated metal covering of aluminium alloy. I understand that a number of designs radically different from that of the present wooden machine are being or have been considered by our own Air Ministry, and I do not doubt that something after the type of the cantilever design may be the best in the future for main planes. With regard to the final paragraph in Mr. Duncan's communication, the apparent discrepancy is mainly due to the fact that the moment of inertia of these two spars differed rather widely, giving, therefore, a large difference between the maximum fibre stress at equal load factors.

A NEW TYPE OF SHIPYARD CRANE.

By W. Hök (Member).

17th February, 1920.

Introduction.

Some eight years ago it was decided by the Lindholmen Shipbuilding and Engineering Company of Gothenburg to demolish two of their three existing shipbuilding berths suitable only for the construction of small ships, and on an enlarged site to lay down three new berths for the construction of ships up to 12,000 tons deadweight. For this purpose about 500,000 cubic feet of solid rock had to be removed.

In the spring of 1913 it became imperative to decide what kind of hoisting appliances should be adopted for the new berths, and in June of the same year I set out to visit about 40 shipyards in Denmark, Germany, Holland, Belgium, England, Scotland, and Ireland in the order named. These 40 yards I saw from inside the gate, but many others in the neighbouring localities I viewed from the outside only, either from land or river, a procedure sufficient when my object was the study of shipbuilding berth cranes only.

Previous to going abroad I was aware of the very expensive arrangements used, for instance, by Messrs. Blohm and Voss and the Hamburg Vulcan Company at Hamburg; by the Stettin Vulcan Company at Stettin; by Messrs. Swan and Hunter on the Tyne; by Messrs. Harland and Wolff at Belfast, etc.; and, further, I knew of most of the published super-expensive arrangements used in the United States. I was not, however, in search of an expensive arrangement, but of an efficient and

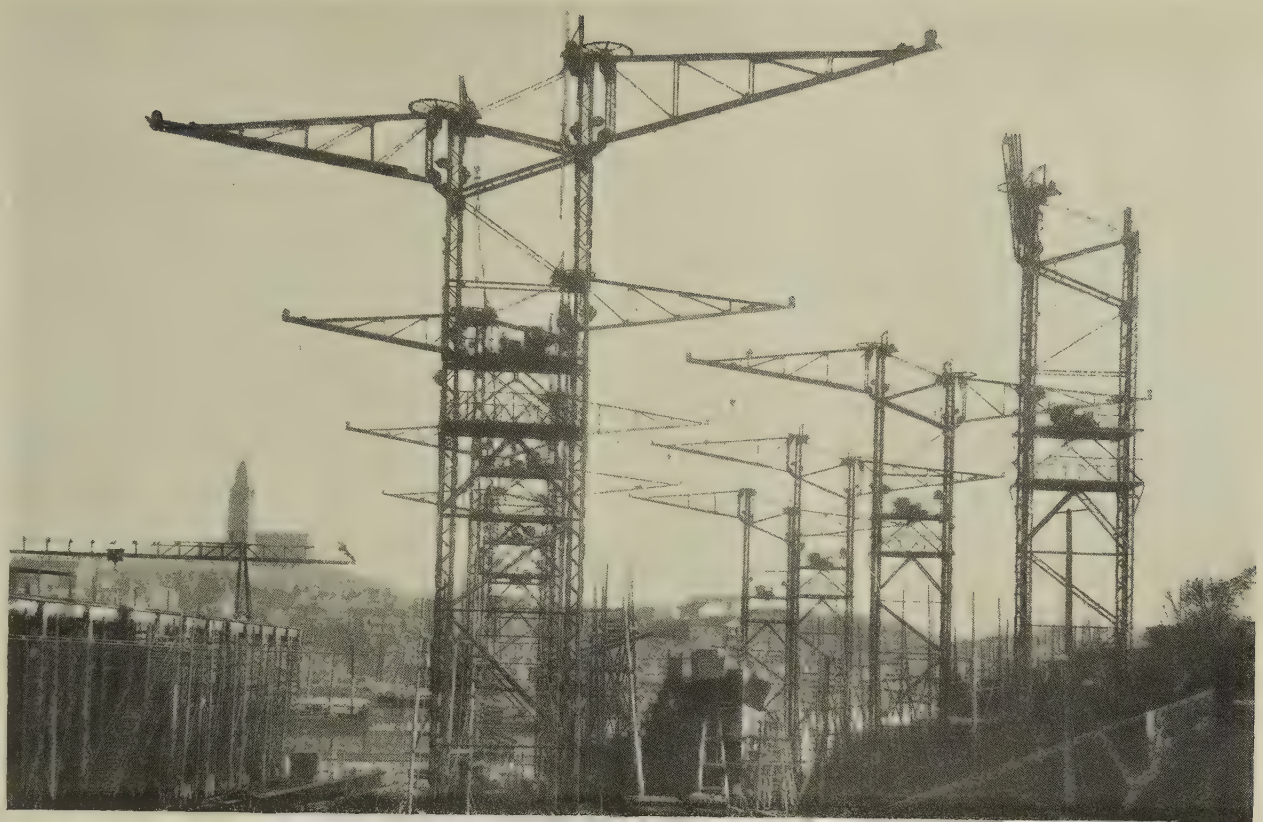
at the same time comparatively inexpensive one, such as a shipbuilding company with a modest purse could afford to adopt.

During my travels I found that a large number of very efficient and fully competitive yards, both in Great Britain and abroad, adhered to the ordinary mast and derrick arrangement, some using wooden masts with wooden derricks, others lattice masts with lattice derricks, or mixed. Invariably the hoisting winch, whether steam or electric, common to two or more derricks, was placed on the ground level, with the attendant trouble of having the hoisting rope leading from the winch to the derrick mast always entangled in bars and plates, staging uprights, and all sorts of rubbish. Besides, signal men placed here and there were part of this equipment, as the winch operator could not as a rule see what he was doing. Other yards were equipped with all kinds of expensive overhead travelling-cranes—gantry cranes, for instance, consisting of a very high and expensive steel structure on each side of the building berth, on which travelled a heavy overhead crane extending right across the berth. Others again were equipped with cantilever cranes common to two contiguous berths, and running either on rails laid on the ground or on a high gantry erected between berths. Some yards were provided with revolving cranes, movable the whole length of ship. And of these revolving cranes the same story can be told as before. Either a high tower-crane travelling on rails laid on the ground or a smaller revolving crane running on rails laid on a gantry erected between berths. In one yard I saw ordinary steam revolving-cranes running on rails laid on a gantry of moderate height erected at each side of the building berth. In this instance the gantry was so built that it could be moved sideways for the whole of its length, if necessity should arise for building broader ships on this particular berth than was originally intended; while in other yards stationary revolving tower-cranes were used.

But what struck me most of all was that, on the whole, nobody seemed entirely satisfied with the crane arrangements he possessed. This conclusion I came to, partly by the views expressed to me by the parties concerned, and partly by the fact that in shipyards having a number of building berths the same system of berth cranes was never carried consistently through. On the contrary, it was almost always the case that a different system of cranes was tried at almost every building berth in the same yard and for every new berth laid down. Further, I noticed that on the whole the tendency was to discard very expensive crane sheds, covered in or not, and to substitute cheaper arrangements.

In a very famous yard in the North of Ireland stationary revolving tower-cranes were thus being erected in lieu of covered-in sheds, and in another yard in the same district high revolving tower-cranes movable on rails laid on the ground had just been erected between the berths, but these cranes were not allowed to be moved more than once a day. In another yard, which I know well, the travelling tower-crane is not allowed to be moved at all until the section of the ship covered by the crane is completely erected. In a well-known yard in the North of England, which I visited in the summer of 1919, a yard also known for expensive sheds carrying overhead travelling-cranes, I found that a new building berth had been recently laid down, and in this particular case a very modest hoisting arrangement adopted consisting of lattice masts with two lattice derricks on each mast, all in connection with electric winches placed on the ground level.

From what I had seen I could not help drawing the conclusion that those builders who had in the past gone in for very expensive berth cranes were not wholly satisfied with their investments, having undoubtedly found that the efficiency of their hoisting gear was not commensurate with its cost, and, further, that after all they could not with their expensive crane arrangements do much better than their neighbours working



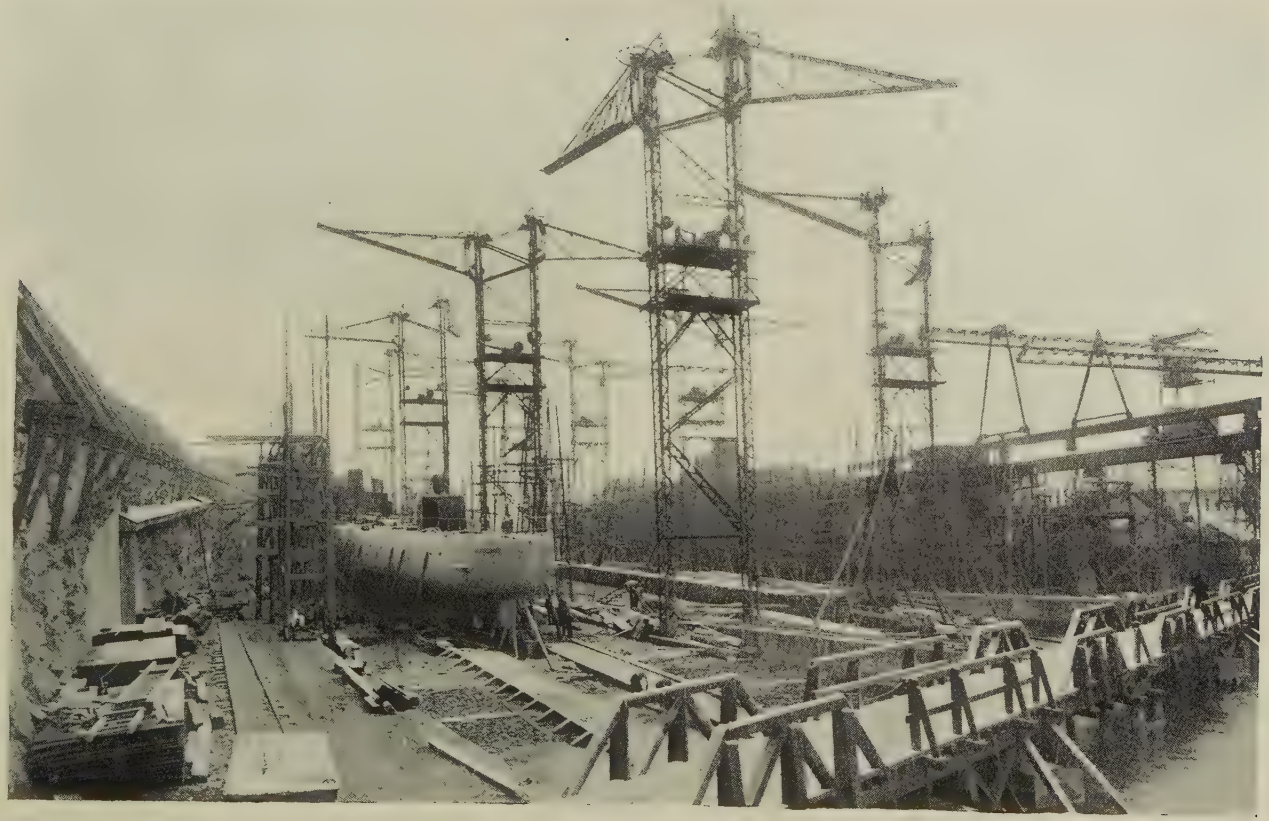


Fig. 2

with simple and comparatively inexpensive appliances. I thus decided in favour of a simple and comparatively inexpensive crane arrangement.

After considerable thought, and having turned things over in my own mind, I came to the following broad conclusions:—

(1) The mast and derrick arrangement is quite satisfactory, provided it can be so arranged that all side staying of masts can be done away with.

(2) The operator's platform should be placed high up above the ground on, for instance, the level of the principal weather deck of the ship, so that the operator can see what he is doing, thus obviating the necessity of using signal men.

(3) The lead from the hoisting winch to the derrick mast should not be taken along the ground among staging uprights, shoring, plates and bars, and various rubbish strewn about the ship. The lead from the winch should be free from all obstructions.

(4) A space or passage-way is desirable between contiguous ships to enable building material to be brought down between ships and hoisted on board from the nearest point at the ship's side, and not from the ship's end only. Such an arrangement covers many more chances of rapid building than an arrangement based, for instance, on the material being taken in hand by the hoisting gear at the end of the ship only, because the former arrangement offers so many more points of attack on the ship than the latter.

Description.

Guided by the leading features just mentioned, I designed the stationary building-berth crane which is described and illustrated in Figs. 1 to 4, eight of which are erected at the Lindholmen Works, and have been in good use since 1914. In this connection it will be noticed, by referring to Figs. 1 and 2, that the only one remaining of the old building berths at Lind-

holmen, on the right in Fig. 2, is fitted with a high gantry and a couple of overhead travelling-cranes, an arrangement some 15 years old which I could not afford to demolish.

It will be seen by the plans, Figs. 3 and 4, that the new type of berth crane is chiefly composed of a stationary main structure and two swinging arms, the former consisting of two lattice-work masts placed about 15 feet 3 inches apart from centre to centre, and rigidly connected to one another by cross stays and trusses, making the main structure stable in the thwartship direction, thus obviating the necessity of fitting the objectionable side-stays which are an inevitable essential of the ordinary mast and derrick arrangement. A structure, such as the one depicted, consisting of two derrick masts rigidly connected to one another by cross stays and trusses, I have subsequently taken the liberty of calling a *derrick frame* in contradistinction to the solitary derrick mast.

Each derrick frame carries two derricks or arms A, as shown, which can swing about 120 degrees to each side of a vertical thwartship plane through the derrick frame, *i.e.*, well past the centre line of railway B, Figs. 3 and 6, laid down in the passage-way between contiguous ships. The derrick frame is held in place by fore and aft wire stays only, as shown in Figs. 1 to 5, *i.e.*, by two sets of stays, the lower ones C, in Figs. 4 and 5, being fitted, partly for giving rigidity to the frames in a fore and aft direction, and partly for preventing collapse of a whole group of interconnected cranes in case for some reason the top end stays R, Fig. 5, or some of the top stays D, Figs. 4 and 5, fitted from crane top to crane top of that group should give way.

At a suitable place above the ground two operators' or winch platforms E, Figs. 3, 4, and 5, are built into the derrick frame, the one above the other, access to which is obtained by ladders inside the frame legs F, Figs. 3 and 4.

Each crane arm and the load are in the present case controlled from their appropriate aerial platform E by a single ordinary alternating-current electric shipyard-winch G, Figs. 3

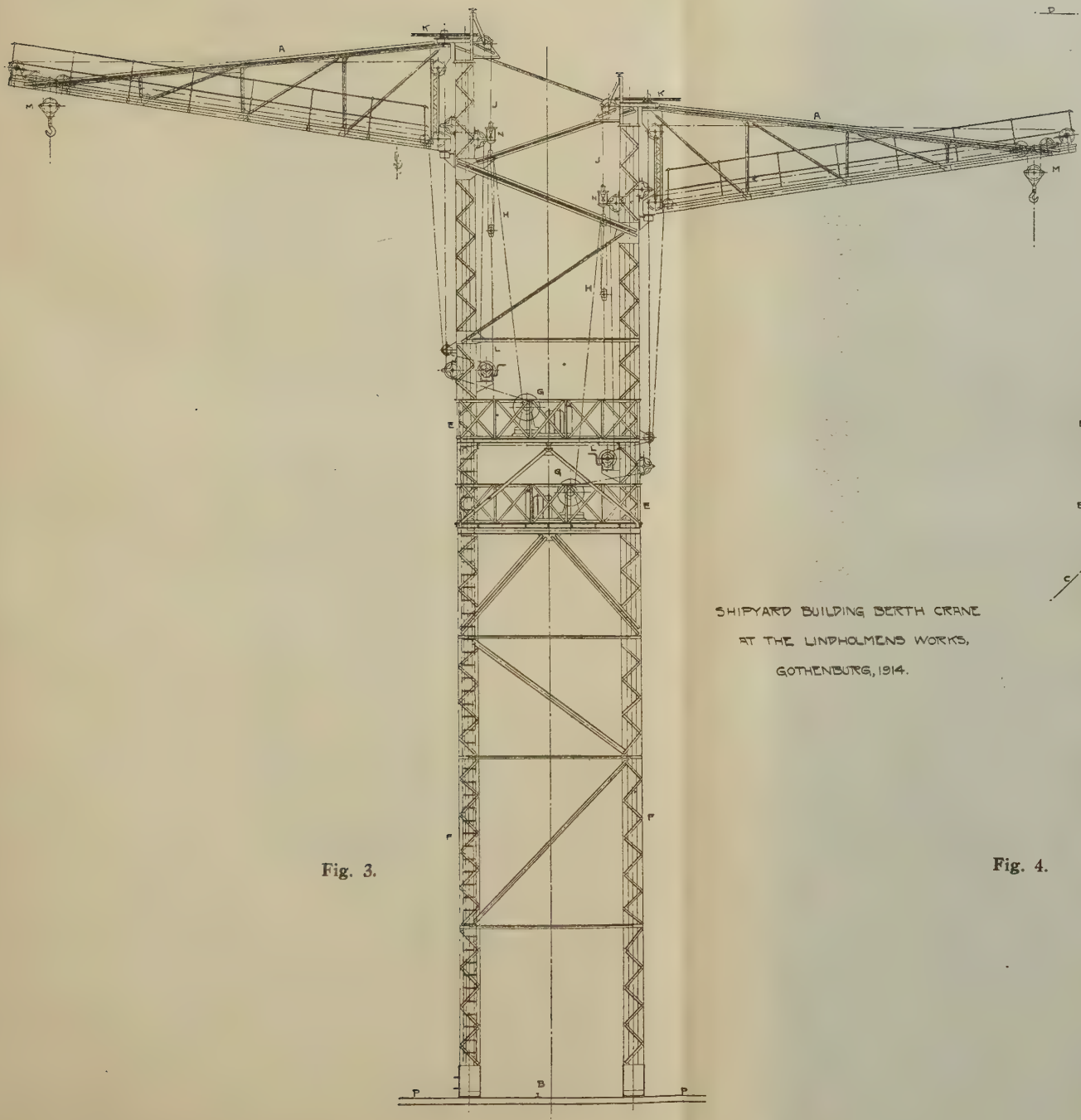


Fig. 3.

SHIPYARD BUILDING BERTH CRANE
AT THE LINDHOLMENS WORKS,
GOTHENBURG, 1914.

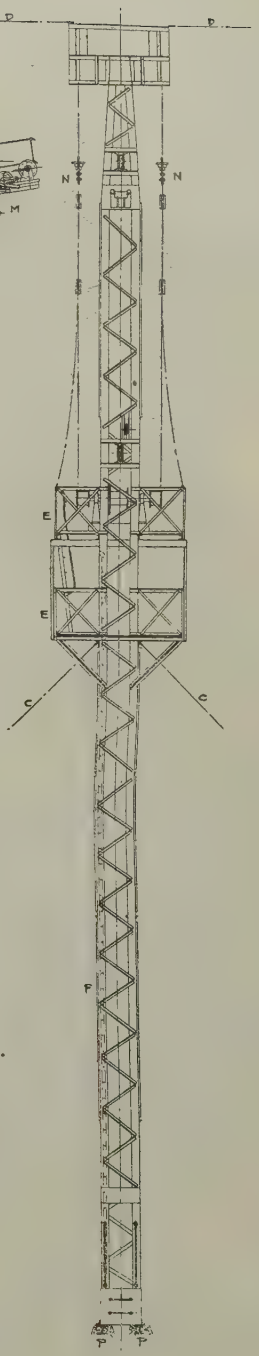


Fig. 4.

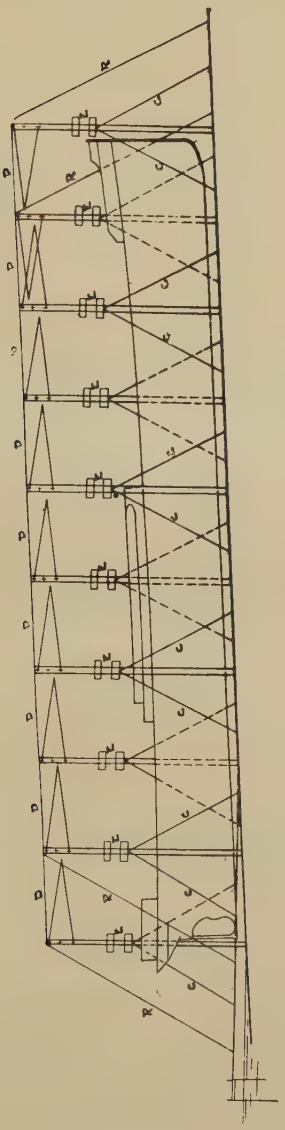


Fig. 5.

and 4, that is to say, controlled by one electric motor only. *Hoisting* and *lowering* are done with the winch centre barrel in the ordinary way, and *slewing* with the extended winch ends by taking a couple of turns round the appropriate extended winch end with the loose end of a tackle H, Figs. 3 and 4, actuating the wire J which, as shown in Figs. 3 and 4, is carried round and fastened to the rim of the horizontal wheel K on top of the crane. The wheel is fixed to the top centre pin of the crane arm.

It is perhaps necessary to mention that a spiral spring N is introduced above the slewing tackle, Figs. 3 and 4, for the purpose of taking up the inertia of the crane arm when it arrives at the extreme end of the swing, in this way preventing damage and unnecessary straining of the connections in case of rough usage or ignorance on the part of the man handling the crane. For the crane is so easy to manipulate that any ordinary platers' helper or labourer can officiate.

Racking is done with a small hand winch L, Fig. 3, only. It is here to be remarked that, for my own part, I do not attach much importance to the racking motion, and hold that if the cranes are high enough there is no necessity for adjusting to such a nicety the position of the trolley M, Fig. 3, on the crane arm as to cause the material hanging in the hook to absolutely plumb the point where it is going to be placed. The material can on most occasions be pulled into position without an effort as long as the trolley on the crane arm is approximately where it should be. It will be noticed that the lower member of the arm along which the trolley moves is not horizontal, but slightly sloping. It is in this case purposely so arranged in order to make it comparatively easy to move the trolley towards the outer point of the arm, when there is no weight on the crane hook, and to make it very easy to move the trolley towards the derrick frame when the load is on; and for these reasons the trolley M is always moved, before the weight is on, as

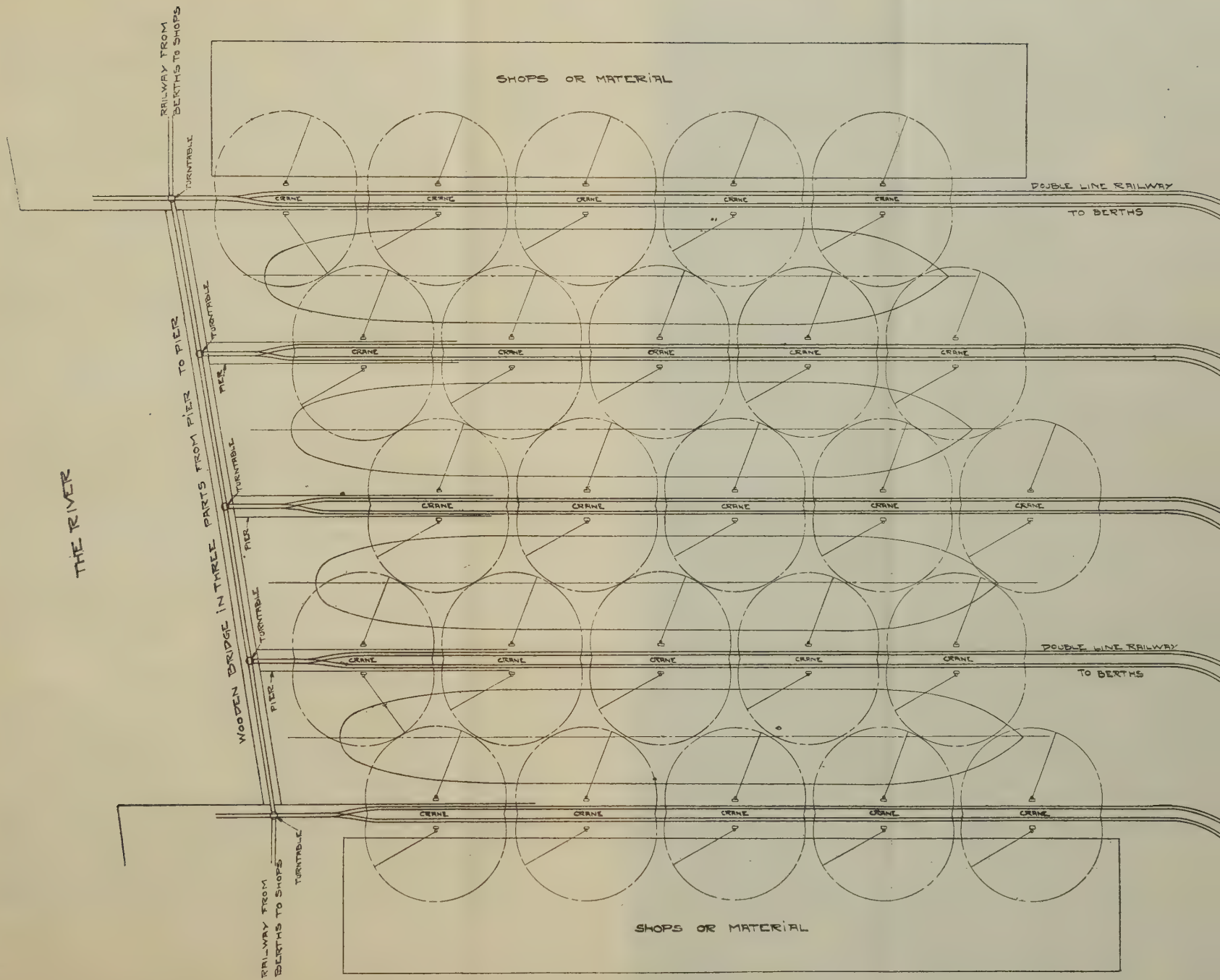

SHOPS OR MATERIAL
RAILWAY FROM BERTHS TO SHOPS
TURNTABLE
DOUBLE LINE RAILWAY
TO BERTHS
CRANE
PIER
THE RIVER
WOODEN BRIDGE IN THREE PARTS FROM PIER TO PIER
SHOPS OR MATERIAL

Fig. 6.

far out towards the extreme end of the arm as considered necessary in each individual case, and it is then afterwards a very simple matter to adjust the trolley in the direction of the derrick frame, if necessary, after the load is on. In practice this method has shown itself satisfactory and quite sufficient.

But apart from this reasoning and experience, it should be understood that if anybody should prefer to manipulate the crane with three motors, one for hoisting, one for slewing, and one for racking (the member on which the trolley travels being in that case horizontal), it can, of course, be easily done. The method I have adopted is, however, in my opinion satisfactory and quite sufficient, and it certainly has the merit of being simple and inexpensive.

The frame legs stand on joists P, Figs. 3 and 4, laid thwartship, and about 3 feet apart—*i.e.*, the fore and aft dimension of the frame legs apart. These two joists are securely fixed to the solid rock, and the frame legs are securely bolted to the upper flanges of the joists. In this way is the transverse stability of the crane doubly secured.

The present cranes were built flat on the ground. Since the arms had been fitted on to the frames and secured, the cranes were raised into a vertical position, and then screw-jacked into their absolute position.

Dimensions and Capabilities.

The frames of the present cranes have a height above the ground of 110 feet, the section of each frame leg is 22 inches wide by 36 inches in a fore and aft direction. The crane arms are about 40 feet long, the upper winch platform is about 60 feet above the ground, the lower platform is about 8 feet below the upper one, and the height from the ground to the underside of crane hook in its highest position is about 90 feet. Ball bearings are fitted throughout. The clear distance between the frame legs is 13 feet 6 inches, thus admitting

one or perhaps even two parallel railways between the frame legs and between contiguous ships. It will thus be seen that with these cranes 22 feet only are required between contiguous hulls, counting 28 inches from the crane leg to the hull side, which distance is quite sufficient when pneumatic riveting hammers are used. If 22 feet are not available between adjoining hulls, this distance can be made somewhat less by reducing the distance between the frame legs. The structure is stable sideways all the same as long as the frame legs are securely fastened to the ground.

It is to be explained that at Lindholmen uprights for carrying the stage planking surrounding the vessel are not nowadays used, except at the extreme ends of the vessel. For such support angle brackets are now bolted to the shell plating —an arrangement which is much tidier and less obstructive, and which takes up much less room in a thwartship direction than the old method with uprights.

The present cranes were built to lift 2½ tons at the extreme end of the arm. But it was soon found that they could be put to better use if some of them could be made to lift a heavier weight. The whole crane calculation was then gone into again, and it was found that with a slight strengthening of the lower members of the arms and of a few connections the cranes could, without undue straining, be made to lift 5 tons at the extreme end of the arm and 10 tons at about 10 feet from the derrick frame. Since this strengthening took place there has been, for ships up to 7,000 tons deadweight, lifted on board and lowered into position while the ships were still on their building berths, every particle belonging to them, including the main engines, with the exception, however, of the boilers, uptake, and funnel, and this summer it is intended to launch ships of 8,000 tons deadweight, having their engines completely erected in place on board. It must, however, be explained in this connection that engine-room weights exceeding 5 tons are first lifted on to the ship's deck by a

single crane, and then two or three of the cranes surrounding the engine-room are combined for the purpose of lowering the weights down the engine-room hatch.

I have, further, to draw attention to the fact that one group or both groups of cranes surrounding a ship can be shifted sideways without great difficulty, the joists on which the cranes stand being made specially long for this purpose, which device is useful to have in hand in case it should be considered advantageous to build a broader ship on the building berth than can go between the cranes in their present position. For instance, for berth No. 3 the cranes are now set for ships up to 65 feet in breadth, but they can be shifted sideways on the joists so as to admit ships 80 feet broad by sacrificing adjoining berths to a corresponding extent. But it is evident that it would only be in case of a very tempting contract or of urgent necessity that one would thus shift the cranes, for the fore and aft wire stay ground attachments and the railway situated between the berths would necessarily also have to be moved. But, in any case, with this system of cranes shifting the cranes sideways can be done, if necessary, and almost as easily as with the ordinary solitary mast and derrick arrangement.

The cranes can, naturally, be placed as close together as one may like in the direction of the length of the ship—for instance, as close together as ordinary masts and derricks are generally placed, and the crane arms can, of course, within reasonable limits, be made as long or as short as one might fancy, either overlapping each other or not. All this is a matter of taste or requirement.

It is perhaps, then, not inappropriate finally to point out that the present crane design is very elastic—that is to say, the dimensions and capabilities of the crane can be varied within considerable limits, such as in regard to lifting power, length of arm, distance between crane legs, etc., without loss of any features inherent in the design of the crane.

Regarding the saving of labour cost and increased rapidity of building due to these cranes, I regret to say that I cannot as yet speak authoritatively on that point, simply because the cranes have not so far, from want of a sufficient supply of steel material during the war and after, been fully tested.

Weights and Cost.

Each crane, including one complete frame and two arms, but excluding winches and hoisting wire, weighs about 33 tons.

As regards the cost, it is fairly evident that these cranes are cheaper than any other existing hoisting appliance with the exception of the ordinary mast and derrick arrangement. They are, however, considered to have special advantages over the latter arrangement which should repay the extra outlay for them.

Regarding the actual cost of the Lindholmen cranes, eight of them, including 8 derrick frames, 16 derrick arms, 16 winches, the necessary hoisting wire, stays, blocks, foundations, etc., erected all complete, cost about £11,500—*i.e.*, something less than £1,500 for each double-crane—but as this figure is a pre-war figure it is to-day of comparatively little value.

Reflections.

I hold the firm belief that to build rapidly, a ship should be simultaneously attacked from as many points as possible, and chiefly from the sides, and not wholly from the upper end. Congestion of traffic must ensue in the latter case, whereas in the former it is essential that a clear passage-way be arranged between adjoining ships through which the material can be easily transported to its proper place at the side of the ship. See Figs. 1 and 6. The material should be transported on light trucks, running on rails, down this passage-way to its respective crane hook, and the empty truck should be immediately moved on and returned to the sheds a differ-

ent way from which it came, as shown in Figs. 2 and 6, so as to prevent the railway line being blocked and the circulation of traffic impeded. For this transporting work I prefer the light truck to the heavy, cumbersome steam locomotive-crane, partly because the number is practically unlimited in a yard, and partly because it is easily thrown off the line if it is in the way, which summary procedure cannot be adopted in the case of the latter. And, after all, the men should be doing something in the meantime, and not merely be hanging about doing nothing, while a solitary steam crane—or a couple of them—at a very slow pace brings forward material to the building berths.

I believe that a double railway line, Fig. 6, between adjoining building berths is preferable to a single line, for fairly often the traffic is impeded if the line is single, with a consequent loss of valuable time. It is therefore advisable to make the distance between the frame legs of the cranes sufficiently great for eventually admitting a double railway line between them, which can easily be done by fixing the clear distance between the legs to nothing less than, say, 15 feet, for instance.

For what it is worth, I present a schematic outline of a building yard laid out according to these ideas.

Discussion.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member): This paper contains not only a most lucid description of a somewhat novel arrangement of shipyard crane, but also one of the most interesting and complete summaries of the whole problem of transportation and lifting in shipyards that has been published. A sad commentary on the condition of some shipyards appears where the author, speaking of the hoisting rope from a winch on the ground, says it is "always entangled in . . . all sorts of rubbish." Now a shipyard is not the place for rubbish, and no doubt the attention thus called to the matter will result

in inquiries, and a very desirable improvement by the elimination not only of rubbish but of unnecessary gear and material lying about in a casual manner. Apropos of the mast and derrick arrangement, it may be noted that it is not an essential part of the arrangement that the hoisting winch should be at the ground level. Indeed, one might say that in most modern outfits of that type the hoisting and other machinery is carried high up on the mast.

Regarding Mr. Hök's observations on the more elaborate outfits, especially his summary on page 268, it appears to me that the problem of the best type is not capable of any rigid solution. There is no optimum arrangement in the strictly mathematical sense and even leaving aside future developments and improvements, I would suggest that Mr. Hök should consider what would probably happen at Lindholmen in the event of a successor of his having to further extend the yard and its equipment. It is probable that, however satisfactory the present arrangement may be under the existing regime, some other arrangement would be adopted under the circumstances indicated.

As a solution of the mast and derrick arrangement, Mr. Hök's scheme is most admirable, and having got rid of guys in one direction, a logical improvement would be to proceed from a group of two masts stable in one direction to a group of three or four or even more entirely self-supporting; in fact to the construction of something not unlike the fixed portion of a tower crane fitted, however, with derricks at the corners instead of with a cantilever on top. The Lindholmen shipyard possesses one great advantage in being built on rock. This enormously simplifies the problem of foundations for cranes and other machinery, with, no doubt, some disadvantage as regards piping arrangements and so forth.

The structural design of the crane was no doubt largely conditioned by the material available, and many approximately equally good designs could be got out embodying the main

Mr. W. H. Riddlesworth, M.Sc., M.Eng.

principle of self-contained support in one direction and guy-provided support in the other, incidentally affording many interesting problems in structural design, which are somewhat off the beaten track. The mechanical arrangements of the crane are, as the author says, "simple and inexpensive," simple almost to the verge of crudity. Our Swedish friends must be fortunately situated in the matter of labour if they can arrange to have one man, and that one of the labourer type, who is willing and able to "officiate" at a crane which requires the manipulation of a loose rope on a warping barrel for slewing and the turning of a hand winch handle for racking in addition to his duties at the hoisting winch. But, as is pointed out, three motors can be fitted if thought necessary or advisable. Neither slewing nor racking gear is fitted in many derrick installations, and yet the work proceeds with fair speed. Mr. Hök's remarks about space between contiguous hulls are interesting and useful, and further particulars of the method adopted for supporting staging and of the necessary order of erection of material would be greatly appreciated.

The question of the lifting power of a shipyard crane is one of the utmost importance, and the easy solution of the problem of increasing the desired load, which arose so soon after the erection of these cranes, points to the fact that very liberal margins of safety must have been adopted in the first instance. The use of two or three cranes for dealing with abnormal loads appears to me to be excessively risky, as equalising devices are not simple nor are they easy of application, but like many other theoretically undesirable arrangements it comes off, and probably will come off until, like the pitcher that went too often to the well, it fails with very serious consequences.

Mr. Hök's reflections at the end of the paper are worthy of the most earnest study, and form a concise statement of principles, that have not altogether been neglected by those who have had the task of arranging shipyards, either in this or other countries, as may be seen by consulting the all too scanty records of shipyard arrangements.

Mr. J. H. Huntley.

Mr. J. H. HUNTLEY (Member): As Mr. Riddlesworth pointed out, Mr. Hök has brought to our notice a comparatively cheap and fairly efficient type of crane suitable for a small yard with limited resources. In summarising his investigations as to the best type of shipyard lifting appliances, I think he should give credit to what he saw on the Clyde. Three of the desirable features stated on page 269, namely—(1) the operators' platform placed in an elevated position, (2) the lead from the hoisting winch quite clear from the ground, (3) clear passage between contiguous berths—are to be met with on derricks erected on the Clyde from 10 to 12 years ago. Further, the racking and slewing motions are operated by power, which is a step in advance of the arrangement adopted by Mr. Hök. His remarks about shipbuilders not being satisfied with their existing arrangements may have been quite true several years ago, but I think, if he visited the various yards now, he would find that those shipbuilders who had adopted tower-cranes of the horizontal cantilever type were well satisfied with them, and anxious to get more for new berths. As pointed out in the paper, the capacity of his cranes, as originally designed, was on the low side, and the fact that these had to be stiffened up to take greater loads points at once to the desirability of having all motions operated by power to secure efficient and rapid working. The bulk of the tower-cranes installed in shipyards are designed to handle loads up to 10 or 12 tons, while some have been installed to lift loads of 30 tons at 60 feet radius and 15 tons at 120 feet radius. It is impossible to handle these loads efficiently by manual power. Mr. Hök mentions that his cranes are operated by one man, who controls the hoisting winch, manipulates the ropes for slewing, and applies himself to the hand winch for racking. I fear he would not get a man to do all that in this country; in any case it must be slow work.

Mr. R. MCLAREN, O.B.E. (Vice-President): I should like to draw attention to the labour charges involved in the arrangement of cranes described in the paper. Fig. 6 shows the plan

Mr. R. McLaren, O.B.E.

of a yard in which there are four berths and 50 cranes. Presumably a man is required continually at each crane, because the crabs being half-way up the masts, it would not be very practicable to send a man to work any individual crane as required, and if this is so, it seems to me that the labour costs of operating would far outweigh the interest on the capital expenditure of a less simple design. These four berths might be efficiently served by four travelling tower-cranes—two cranes between each pair of berths—the range of the jibs being such as to cover both sides of the vessel under construction. Even if a more liberal provision were desired, say, six such cranes, the difference between the wages of six and 50 men at the rates prevailing at the present day would be very great, and would amply justify a considerable capital expenditure. Further, it is a question whether 50 simple cranes would not actually cost as much as the six travelling cranes I have suggested, so that the additional operating labour would be all loss.

Mr. W. Hök: I am much obliged to Mr. Riddlesworth, Mr. Huntley, and Mr. McLaren for their contributions to the discussion on my paper.

Mr. Riddlesworth asks for further particulars of the method adopted for supporting staging, and of the necessary order of erection of material. Although these matters have, strictly speaking, nothing to do with the new type of shipyard crane, I am pleased to give the particulars and submit a sketch, Fig. 7, of the angle brackets used for carrying the men's gangways on the straight, and an illustration, Fig. 8, of a ship during the process of riveting up, where the angle brackets are clearly shown

As regards the order of erection of material, we start from the very bottom of the ship and work towards the top. Thus the keel and the bottom plating are laid up first, then the floors with bars riveted on, tank margin plates, tank intercostals, tank-top, outside tank brackets, pillars, side frames, girders underneath beams, main deck beams, bulkheads to

Mr. W. Hök.

main deck, main deck plating, upper deck beams, upper deck plating, etc. To lay-up the bottom plating first is a good plan, because one has immediately the necessary support for the floors. It even happened in the case of a 7,000-ton steamer that the whole of the bottom plating was riveted up before a single floor was in place. It made a perfect job when finished, and the riveters had a very good time.

Regarding Mr. McLaren's remarks, I do not think that in any shipyard having 50 lifting hooks round the berths 50 crane-

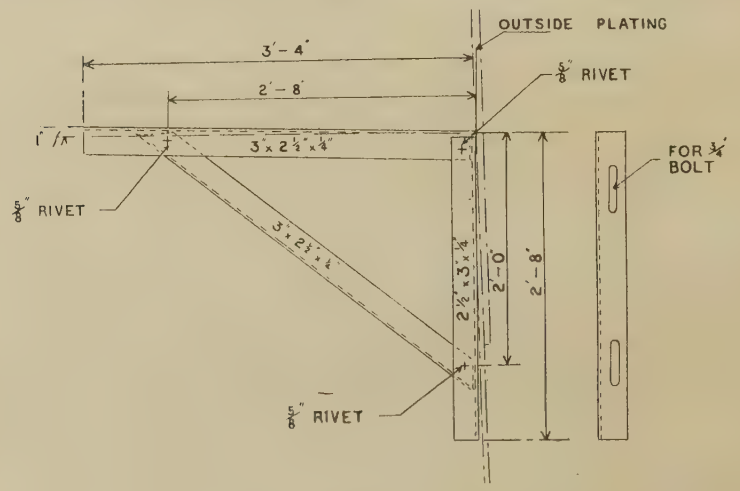


Fig. 7.

men are employed, one to each hook, for the simple reason that in no case are all the hooks used simultaneously. I leave it to Mr. McLaren to work out how many shipyard men would be required to keep 50 hooks going continuously, and how many days a ship would require to be on her berth under such conditions. I am afraid even American war records would then be broken. In this schematic yard, like everywhere else, just the right number of cranemen would be employed—all depending on the speed of building. In my yard, at all events,

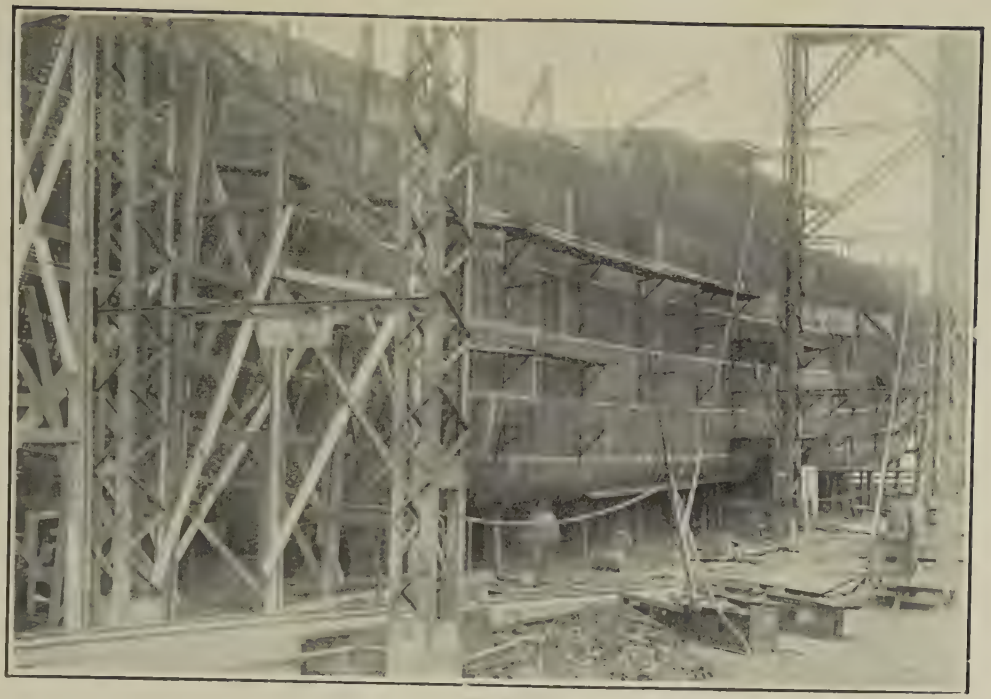


Fig. 8.

Mr. W. Hök.

the men used for the crane winches have no objection in going from one winch to another as required. No shipbuilder having the privilege of 50 derricks and 50 winches round his berths would tolerate the sight of 50 men perched high up in the air all day, unless he could exact from each of them a full day's work, and if he can do that it will pay him to have them up there far better than employing a few men and a few tower cranes instead.

EXPERIMENTS ON RIVETED JOINTS.

By Dr. James Montgomerie (Member).

30th March, 1920.

The series of experiments described in this paper was undertaken at the instance of the Committee of Lloyd's Register of Shipping, and was carried out at the Proving House in this city.

The information derived from experiments on riveted joints of large size is very limited, and it was considered desirable to possess some reliable information in regard to the physical qualities of these joints when exposed to forces producing stresses of normal magnitude. It was desired to know under what circumstances separation of the surfaces of the joint takes place, and what is the comparative effect consequent upon the use of different methods of riveting and of steel or iron rivets in ordinary lap-joints, such as are in common use in shipbuilding.

Before proceeding to describe these experiments in detail, it will be convenient to state here the ordinary theory upon which the design of riveted joints rests and to notice the assumptions implicit in it. This theory, as given in text-books, is well known, and is as follows:—

Take the case of a single riveted lap-joint, and consider a strip of such a joint equal in width to the pitch of the rivets.

Let p = Pitch of rivets.
d = Diameter of rivets.
t = Thickness of plates.
m = Distance of rivet from edge of plate.
} Inches.

ft = Tensile resistance of plates.
fs = Shearing resistance of rivets.
fc = Crushing resistance.
} Tons per square inch.
P = Resistance of strip of joint of width (p). Tons.

The following modes of failure are considered:—

(1) The rivet may shear. The resistance to shear is

$$P = fs \times \frac{\pi d^2}{4}.$$

(2) The plate may tear along the line of minimum area of the plate. The resistance to tension is

$$P = ft\,(p - d)\,t.$$

(3) Crushing may take place in front of the rivet, and so destroy the efficiency of the joint. The area of plate or rivet supporting the bearing pressure is dt, and the resistance to crushing is

$$P = fc\,dt.$$

A fourth method of failure is possible, namely, by the plate breaking in front of the rivet; but this is of little importance in ship work. The resistances to tearing, crushing, and shearing are then considered to be equal, and with certain assumed values for ft, fs, and fc a so-called economical relation is obtained between the pitch and the diameter of the rivets and the thickness of the plates.

In the case of multiple-riveted joints a similar procedure is followed. If P be the total force transmitted from one plate to the other by means of the riveted connection, and n the total number of rivets required,

$$P = nfs\frac{\pi d^2}{4} \text{ for lap joint,}$$

and

$$P = nfc\,dt.$$

If the breadth of the plate be b and the number of rivets in one row be m, the tensile strength of a section of the plate through a line of rivets is

$$ft(b-md)t$$

and

$$P = ft(b-md)t.$$

That in outline is the theory governing the design of riveted joints, and some of the assumptions upon which it is based are as follow:—

In the first place it is assumed that the total force transmitted by the joint is uniformly distributed among the rivets, and in the second place it is implied that a uniform state of stress exists across the joint. It is, of course, recognised that with a lapped joint, due to the non-axial pull applied, the material is subject to bending stresses, but even if these be excluded it is difficult to see how the above assumptions can be entertained as even approximately correct. The shape of the joint, and its discontinuous form, must necessarily lead to wide variations in the states of stress at different points, and with that variation the load taken by the different rows of rivets is intimately associated. When there is added to these the element of uncertainty due to the presence of the rivets themselves, it becomes difficult to resist the impression that the theory rests on a precarious foundation.

It is to be noticed also that the result so obtained professes to give an approximate equality of strength *at the point of fracture*. A knowledge of the ultimate strength of the materials employed in shipbuilding is valuable, and many deductions may be drawn from it. But so far as riveted joints are concerned it is much more important to have accurate information in regard to their elastic qualities up to the point represented by the comparative stresses considered permissible in ship construction. If the butt is more elastic than the material above and below it, to that extent its load is transferred to that material; as the experiments proceeded, therefore, an attempt

32—1 in. Diameter Steel Bolts through Plates and Forgings.
Ordinary Mild Steel Plates Used with Planed Edges.
Rivets and Riveting as for Ordinary Shell Butts.
Bolt Holes in Forgings and Plates Drilled.
In riveting, ordinary shipyard conditions have been faithfully reproduced as far as possible.

Mark.	Type of Riveting.	Type of Rivet.
A. 1	Specimen Joint, Hydraulically Riveted.	Iron.
A. 2	Specimen Joint, Hydraulically Riveted.	Steel.
B. 1	Specimen Joint, Pneumatically Riveted.	Iron.
B. 2	Specimen Joint, Pneumatically Riveted.	Steel.
C. 1	Specimen Joint, Hand Riveted.	Iron.
C. 2	Specimen Joint, Hand Riveted.	Steel.

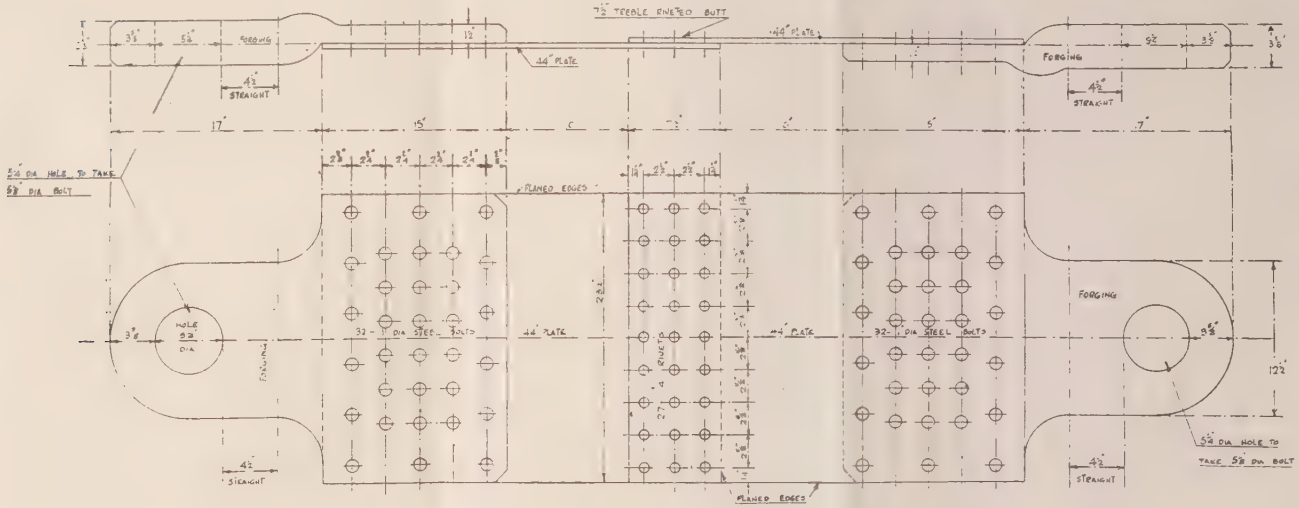


Fig. 1.—Treble Riveted Lap Butt.

Bolt Holes in Forgings and Plates Drilled.

reproduced as far as possible.

26 - 1 in. Diameter Steel Bolts through Plates and Forgings.
Ordinary Mild Steel Plates Used with Planed Edges.
Rivets and Riveting as for Ordinary Shell Butts.
Bolt Holes in Forging and Plates Drilled.
In riveting, ordinary shipyard conditions have been faithfully reproduced as far as possible.

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B. 2	Specimen Joint, Pneumatically Riveted.	Steel.
C. 1	Specimen Joint, Hand Riveted.	Iron.
C. 2	Specimen Joint, Hand Riveted.	Steel.

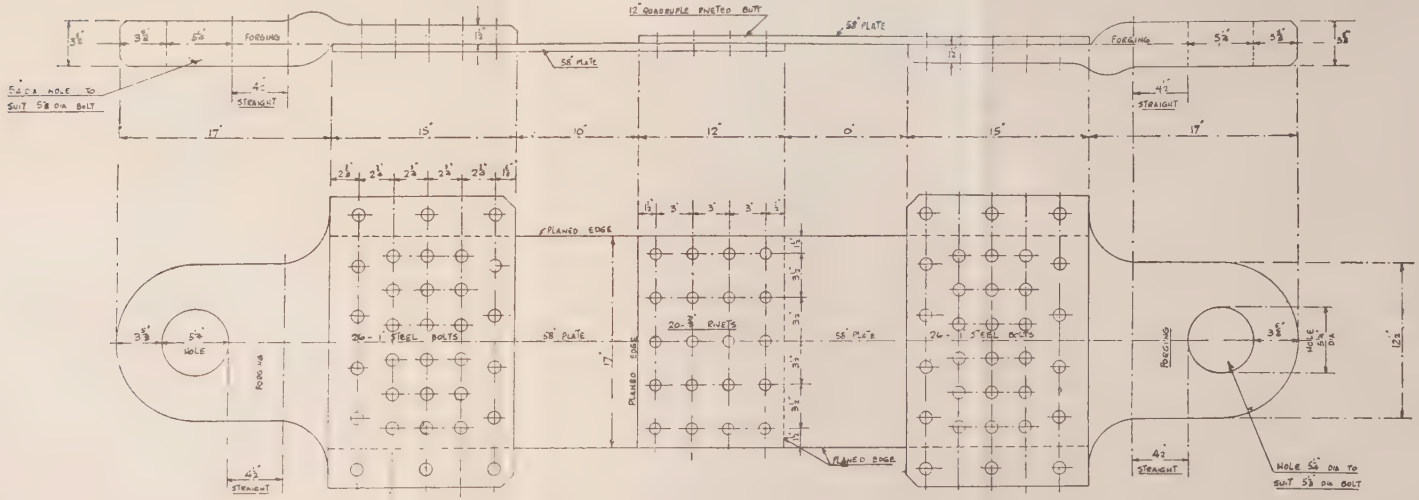


Fig. 2.—Quadruple Riveted Lap Butt.

was made to obtain some idea of the elastic capacity of the specimens experimented upon.

A series of 12 specimen joints was made by Messrs. Harland & Wolff Ltd., Govan, the particulars of which are shown in Figs. 1 and 2. Six treble-riveted joints and six quadruple-riveted joints were designed, the plating and riveting being taken from the rules of Lloyd's Register of Shipping. The treble-riveted joint was effected between plates $23\frac{1}{2}$ inches broad and 0·44 inch thick, and contained 27 rivets $\frac{3}{4}$ inch in diameter. The quadruple-riveted joints were formed between plates 17 inches in breadth by 0·58 inch thickness, and contained 20 rivets $\frac{7}{8}$ inch in diameter. The joints were numbered as set forth below, and instructions were given that no abnormal care was to be exercised in making them, and that the standard of workmanship was to be that obtained in good merchant practice.

Mark.	Type of Riveting.	Material of Rivets.
A1.	Hydraulically riveted.	Iron.
A2.	Hydraulically riveted.	Steel.
B1.	Pneumatically riveted.	Iron.
B2.	Pneumatically riveted.	Steel.
C1.	Hand riveted.	Iron.
C2.	Hand riveted.	Steel.

The plates were of ordinary steel of shipbuilding quality, and were attached to end forgings by means of steel bolts 1 inch in diameter, as shown in Figs. 1 and 2.

In order to carry the strainmeter, holders were prepared, the design of which is shown in Fig. 3. These holders or gauge plates were attached to the two plates forming the joint by means of steel set-pins having sharp case-hardened points. The strainmeter, which has been described elsewhere, was set so that the knife edges engaged with the top surface of the gauge plates, and the strain measured was accordingly the total stretch occurring between the points of the set-pins. The

taking of the observations thereafter proceeded on the usual conventional lines. Pulls of progressively increasing magnitude were applied to the joint. Zero readings were taken by the strainmeter, then a reading corresponding to the pull applied, and finally another zero reading. In order to provide a rough check on the strainmeter reading a pair of micrometer callipers were also employed. Two pins were screwed into the gauge plates in positions shown in Fig. 3, and for each reading taken by the strainmeter a corresponding reading was taken by the callipers.

The joints were extended by the large machine at the Proving House, which is capable of a maximum pull of 180 tons, and throughout the course of the experiments the usual difficulty was encountered which is inseparable from the association of a delicate measuring apparatus with a machine of this power. In addition to that, the experiments were carried out during working hours, and were subject to disturbance by heavy traffic in the street and in the Proving House. It is due to Mr. Seedhouse, the superintendent of the Proving House, to say that it was largely due to his patience and skill in operating the machine that these difficulties were overcome Some reproductions from photographs showing the arrangement of the apparatus are appended.

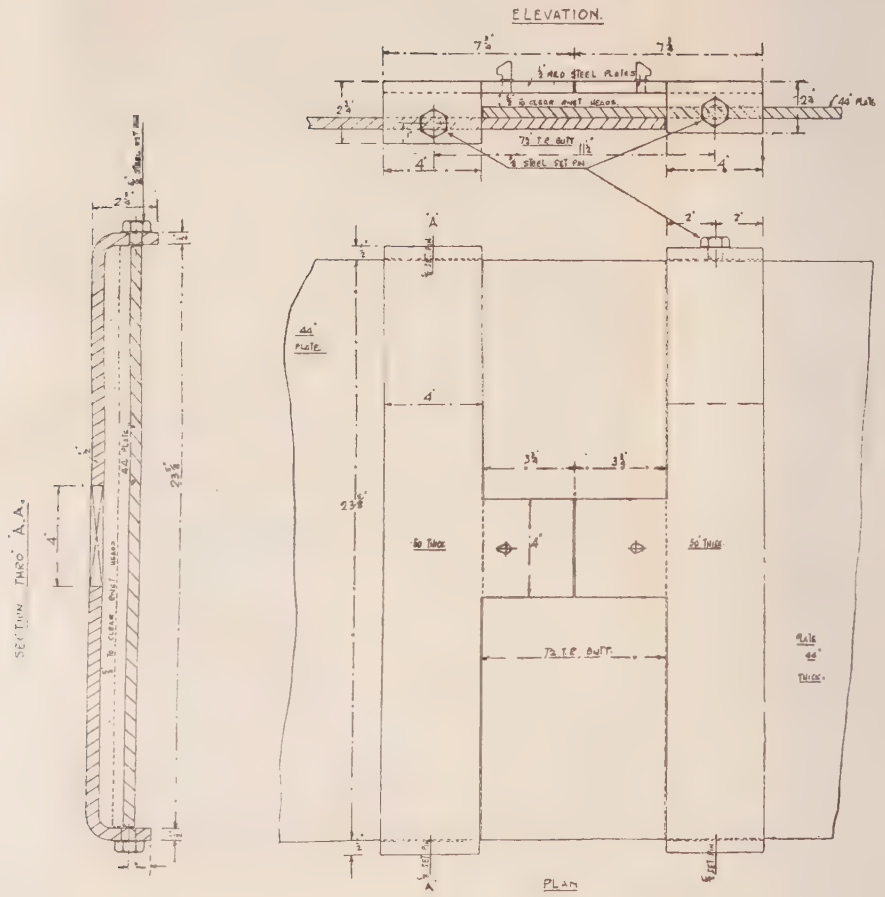
Treble-Riveted Joints—"Slip."

The experiments to detect slip were the most satisfactory of the series. The results were as follow:—

Treble-Riveted Overlap Joints.

Joint.	Riveting.	Pull (tons) at which slip occurred.
A1.	Hydraulic, iron rivets.	95.
A2.	Hydraulic, steel rivets.	92.
B1.	Pneumatic, iron rivets.	92.
B2.	Pneumatic, steel rivets.	85.
C1.	Hand, iron rivets.	95.
C2.	Hand, steel rivets.	105.

GAUGE PLATES FOR $7\frac{1}{2}$ IN. T.R. BUTTS.



GAUGE PLATES FOR 12 IN. Q.R. BUTTS.

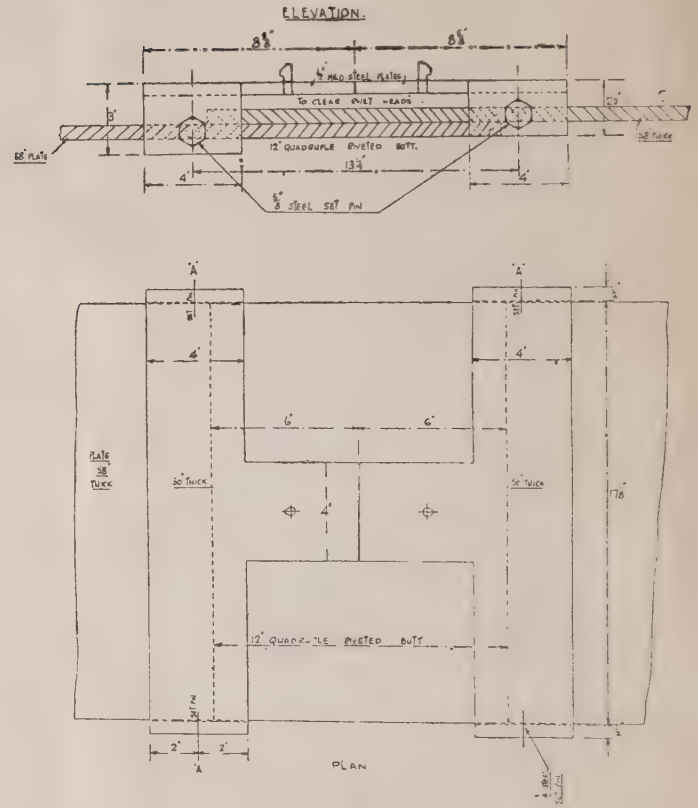


Fig. 3.—Gauge Plates or Holders.

It will be convenient to express these results in terms of the stresses in the unpierced material produced by the pull causing slip, the stress through a line of frame rivets, and also the stress in terms of the rivet area of the joint. The following table gives these results:—

Treble-Riveted Joints.

Table of Stresses corresponding to Pull at which Slip occurred.

Joint.	Riveting. Rivets.	Pull at which slip occurred (tons).	Stress corresponding to pull causing slip. (Tons per square inch.)		
			Over area of rivets.	In unpierced plate.	Through line of frame rivets spaced seven diameters apart.
A1.	Hydraulic. Iron rivets. Snap heads and points.	95	8·0	9·3	11·3
A2.	Hydraulic. Steel rivets. Snap heads and points.	92	7·7	9·0	10·9
B1.	Pneumatic. Iron rivets. Snap heads and countersunk points.	92	7·7	9·0	10·9
B2.	Pneumatic. Steel rivets. Snap heads and countersunk points.	85	7·1	8·0	9·9
C1.	Hand. Iron rivets. Pan heads. Countersunk points.	95	8·0	9·0	11·0
C2.	Hand. Steel rivets. Pan heads. Countersunk points.	105	8·8	10·1	12·5

From the foregoing table it appears that the pull producing slip corresponds to a stress related to the rivet area of about 8·0 tons per square inch, to a stress of about 9·0 tons per square inch in the unpierced plate, and to a stress of about 11·0 tons per square inch in the material between a row of frame rivets

spaced seven diameters apart. *That is, the joint behaves as an elastic solid up to the point at which stresses are produced in the material which the designer would consider from a comparative point of view to be somewhat in excess of those generally accepted as reasonable.* It will also be noticed that the results as produced by the different methods of riveting, and by the different material of the rivets themselves, only vary within small limits. That is, so far as slip is concerned, no effective distinction can be drawn as between the efficiency of iron or steel rivets, or between hydraulic, pneumatic, or hand riveting when properly performed.

Although a comparatively limited significance was attached to the breaking strength of the joint, it was deemed advisable, if possible, to obtain some data in regard to rupture. The joints were, therefore, afterwards subjected to uniformly increased pulls up to the maximum capacity of the machine, with the results shown in the following table:—

Table showing Breaking Loads of Treble-Riveted Joints and Corresponding Stresses.

Joint.	Breaking load (tons).	Stresses corresponding to breaking load. (Tons per square inch.)			
		In solid plate.	Through line of frame rivets spaced seven diameters apart.	Stress in rivets.	In material in line of break.
A1.	178	17·2	21·2	14·9	25·0
A2.	At 180 tons pull joint remained unbroken. Evidently on point of fracture.				
B1.	170	16·5	20·2	14·2	24·0
B2.	182	17·1	21·2	15·3	27·8
C1.	180	17·0	21·2	15·1	24·7
C2.	At 180 tons pull joint did not break although much distorted.				

All fractures took place through line of non-countersunk holes except in the case of B2,

So far as the breaking strength of the joint is concerned no sensible distinction can be drawn between the efficiency of the various joints in respect of the method of riveting employed, or of the material of the rivets used.

Quadruple-Riveted Joints—"Slip."

The experiments to determine slip in the quadruple-riveted joints were carried out as before described for the treble-riveted specimens. The plates lapped together were of approximate dimensions, 17 inches by 0·58 inch, and were connected by a lap containing 20 rivets $\frac{7}{8}$ inch in diameter. The results are shown in the following table:—

Quadruple-Riveted Joints.

Joint.	Method of riveting and rivets.	Pull at which slip occurred (tons).
A1.	Hydraulically riveted. Snap heads and points. Iron rivets - - - - -	95
A2.	Hydraulically riveted. Snap heads and points. Steel rivets - - - -	85
B1.	Pneumatically riveted. Snap heads, countersunk points. Iron rivets - - -	80
B2.	Pneumatically riveted. Snap heads, countersunk points. Steel rivets - - -	88
C1.	Hand riveted. Pan heads, countersunk points. Iron rivets - - - -	95
C2.	Hand riveted. Pan heads, countersunk points. Steel rivets - - - -	70

In the case of specimen marked C2, five rivets were drilled out of the joint before being tested for slip. The position of these five rivets is shown on Fig. 4.

A table is given showing the stresses corresponding to the pull at which slip occurred.

Quadruple-Riveted Joints.

Table showing Stresses corresponding to Pull at which Slip occurred.

Joints.	Riveting. Rivets.	Pull (tons).	Stress corresponding to pull causing slip. (Tons per square inch.)		
			Over rivet area.	In unpierced plate.	Through line of frame rivets spaced seven diameters apart.
A1.	Hydraulic. Iron rivets. Snap heads and points.	95	7·9	9·7	11·9
A2.	Hydraulic. Steel rivets. Snap heads and points.	85	7·0	8·6	10·6
B1.	Pneumatic. Iron rivets. Snap heads and countersunk points.	80	6·6	8·1	10·0
B2.	Pneumatic. Steel rivets. Snap heads and countersunk points.	88	7·4	8·9	10·8
C1.	Hand. Iron rivets. Pan heads and countersunk points.	95	7·9	9·4	11·6
C2.	Hand. Steel rivets. Pan heads and countersunk points.	70	7·8	6·9	8·5

In these cases the pull producing slip corresponds to a stress related to the rivet area of about $7\frac{1}{2}$ tons per square inch, to a stress of about 9·0 tons per square inch in the unpierced plate, and to a stress of about 11·0 tons per square inch in the material between a row of frame rivets spaced seven diameters apart.

These results appear to point to the same conclusion as in the case of the treble-riveted joints, namely, that slip occurs at a pull corresponding to a stress in the material which is not lower than that which would be regarded by the designer as satis-

factory. The joint, that is, acts as an elastic solid within the limits of working stress permitted by the designer. Attention is drawn to the last joint shown in the table, viz., C2. In that case an attempt was made to ascertain the effect on the pull producing slip by a reduction in the number of rivets in the joint. Five rivets were therefore drilled out of the joint, and the result shows that slip occurred at a total pull of 70 tons. This, expressed in terms of stress referred to the area of the rivets, is 7·8 tons per square inch, which agrees with the results obtained from the other joints. This appears to indicate that the pull producing slip varies directly as the number of rivets in the joint. Before this can be regarded as established, however, one or two further experiments would require to be made.

In regard to the ultimate strength of the quadruple-riveted joints, all were subjected to the maximum pull of the machine. Two of them were actually fractured, and the following table shows the results, together with the information in regard to stress corresponding to these results.

Quadruple-Riveted Joints.

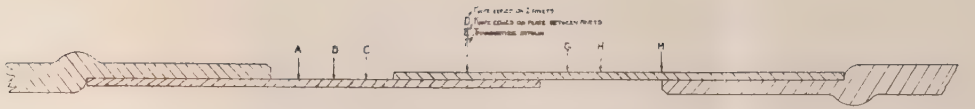
Joint.	Breaking load (tons).	Stress corresponding to breaking load. (Tons per square inch.)			
		In solid plate.	Frame rivets seven diameters apart.	Rivets.	Material actual.
A2.	170·0	17·2	21·2	14·1	23·8
B1.	178·3	17·9	22·3	14·8	24·8

The other joints, while they did not break, were greatly distorted, and evidently on the point of fracture. The whole of the results on this series confirmed those previously obtained, and point to the conclusion that no sensible difference in ultimate strength exists as between the different methods of riveting and material of rivet used.

Elastic Qualities of Joints.

The results set forth above show with sufficient clearness that a riveted joint behaves as an elastic solid up to stresses in the normal material of a certain amount. An attempt was next made to obtain some information in regard to the elastic qualities of the joint, the amount of stretch that took place, and the distribution of stress over its surface. The difficulties in doing so are obvious; the joint may behave as an elastic solid, but it is a solid of extremely discontinuous form. Variations are introduced in respect of the rivet holes, the form and tension of the rivets, the shape of the joint, and the effect of bending. It was not expected, therefore, that the results would show any close degree of uniformity. Arrangements were made to secure a set of progressive readings of the strainmeter for various values of the applied force. First the quadruple-riveted joint C2 was taken, and the strainmeter was placed in various positions on the joint, progressive pulls applied, and the readings taken. Fig. 5 shows these positions, and also the corresponding readings.

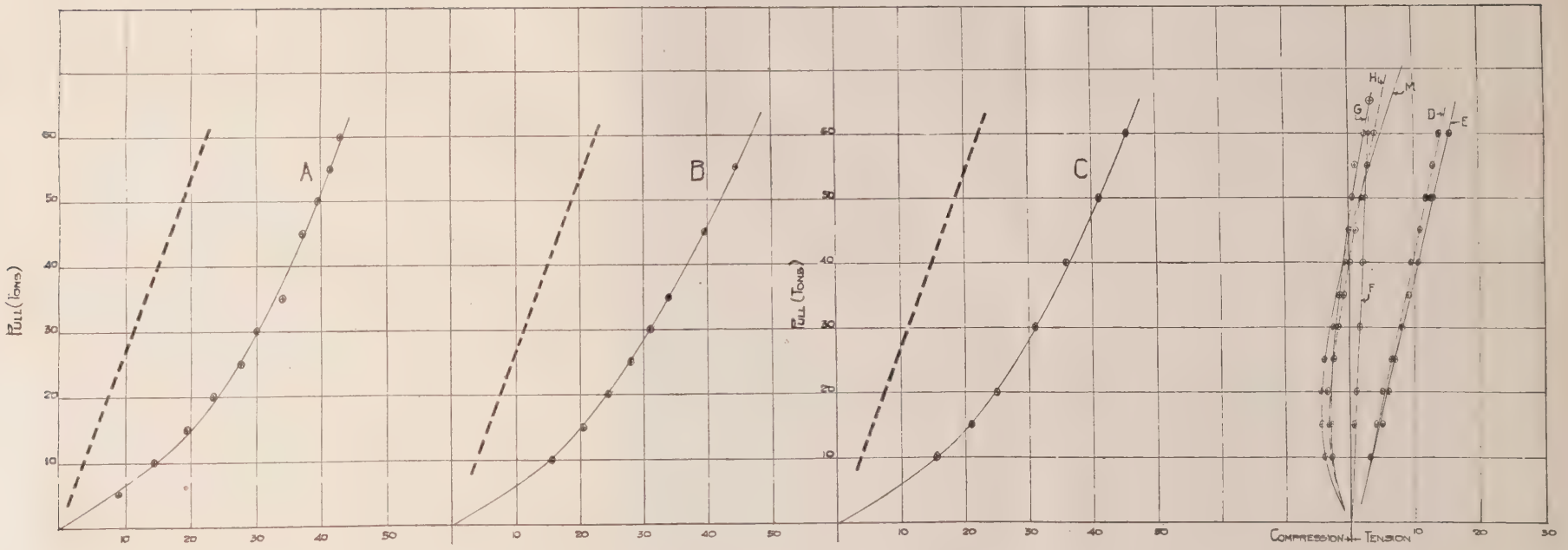
It will be seen that a wide variation of strain (and therefore of stress) is present in the plates. The strains measured over a base of 3 inches, in positions G, H, and M, are negligible as compared with the strains in positions A, B, and C. It should be noted that the positions A, B, and C on the top of the left-hand plate are duplicated on the bottom of the right-hand plate, and similarly the positions G, H, and M have corresponding stations on the underside of the left-hand plate. At station D the strain was measured longitudinally, the knife edges being placed on the points of two rivets; at station E the strain was measured longitudinally, the knife edges being on the plate between two rivets; while at station F lateral strain was measured. The thick dotted line shown on the diagram represents the stretch which would occur in the material of the plate when sustaining the same stresses, and has been found from the



STRAIN DIAGRAM FOR POSITIONS AS SHOWN ABOVE.

Quadruple Riveted Joint C2.

Strain measured on length of 3 inches.



SCALE DIVISIONS OF STRAINMETER

1 SCALE DIVISION = 0·00007"

Fig. 5.

STRAIN DIAGRAM.

Treble Riveted Joint A2.
Hydraulically Riveted with 27—$\frac{3}{4}$ in. Steel Rivets.
Strain Diagram across Plate for Positions shown.

Treble Riveted Joint B2.
Pneumatically Riveted with 27—$\frac{3}{4}$ in. Steel Rivets.
Strain Diagram across Plate for Positions shown.

Treble Riveted Joint A1.
Hydraulically Riveted with 27—$\frac{3}{4}$ in. Iron Rivets.
Strain Diagram across Plate for Positions shown.

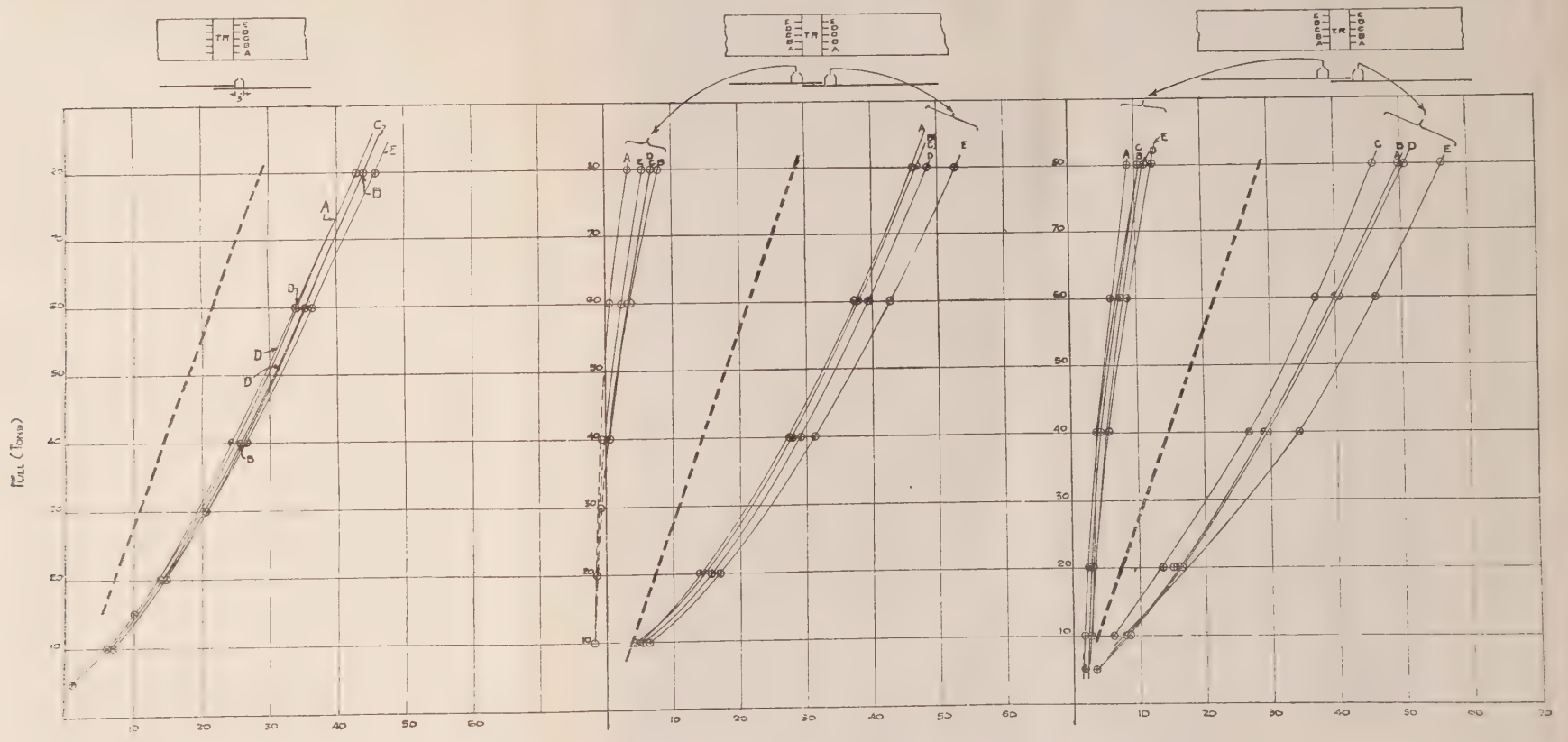


Fig. 6.

STRAIN DIAGRAM.

Treble Riveted Joint C1 Plate 23·3 in. × 0·45 in.
Hand Riveted with 27—¾ in. Iron Rivets.
Pan Heads. Countersunk Points.

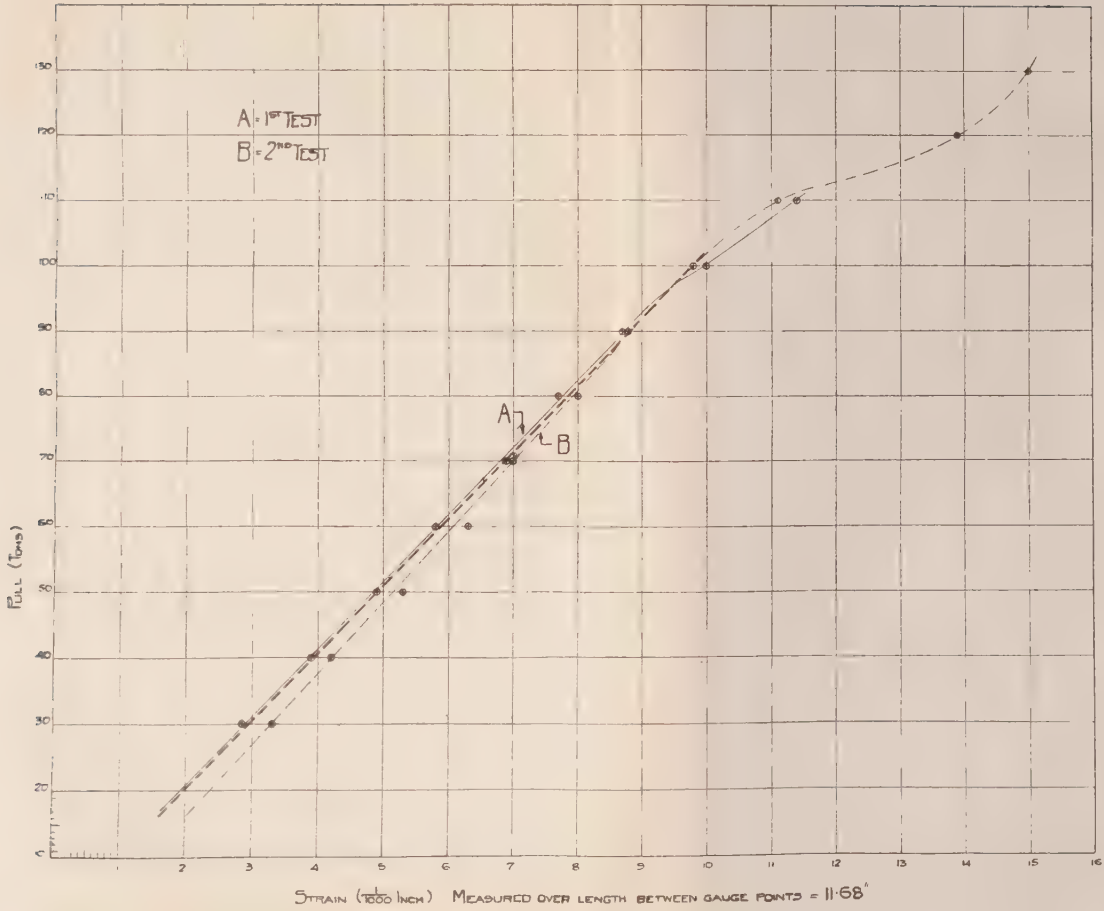


Fig. 7.

STRAIN DIAGRAM.

Treble Riveted Joint C2 Plate 23·5 in. × ·44 in.
Hand Riveted with 27—$\frac{3}{4}$ in. Steel Rivets.
Pan Heads. Countersunk Points.

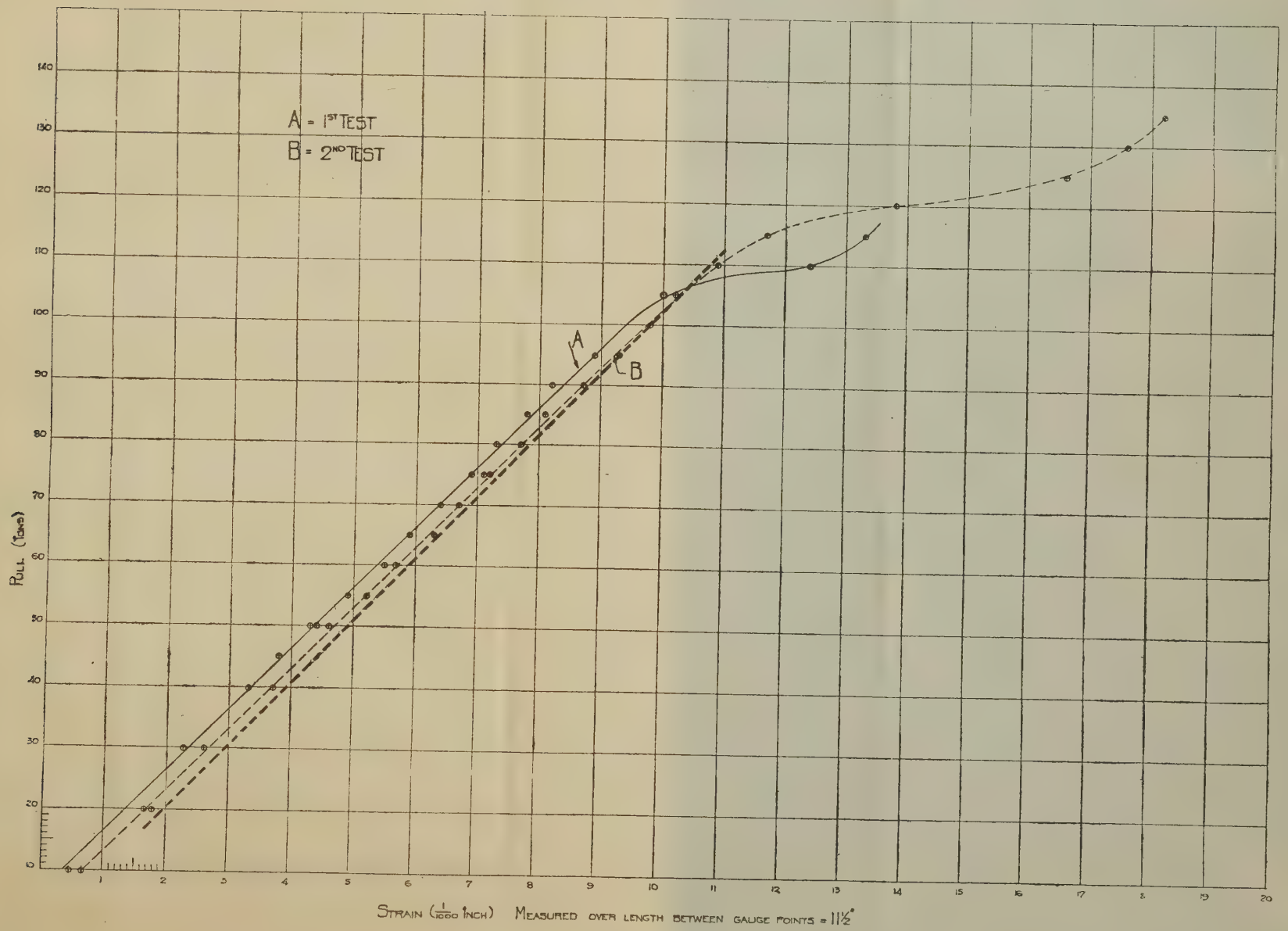


Fig. 8

STRAIN DIAGRAM.

Quadruple Riveted Joint A1 Plate 17 in. × 0·58 in.
Hydraulically Riveted with 20—$\frac{7}{8}$ in. Iron Rivets.
Snap Heads and Points.

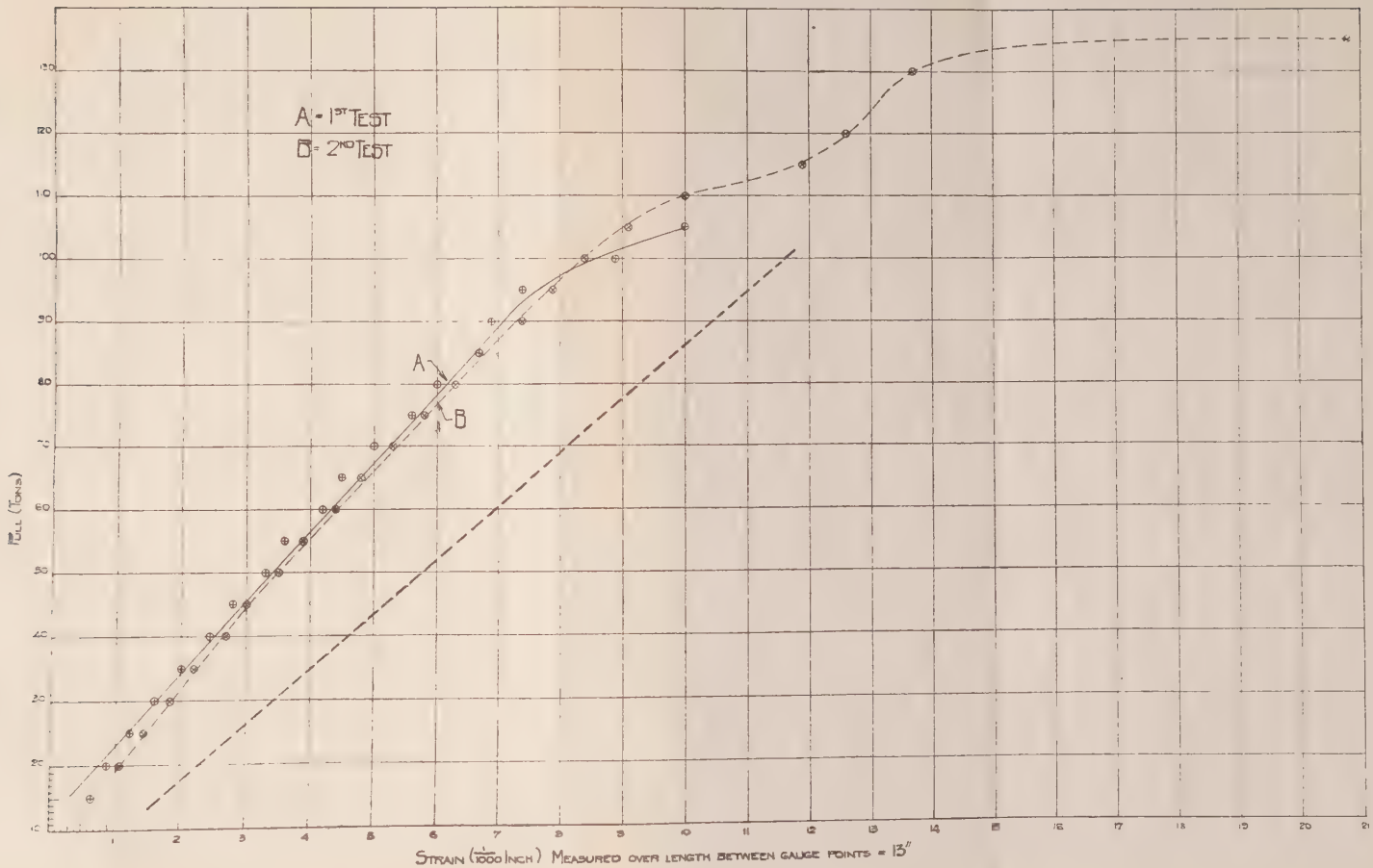


Fig. 9.

STRAIN DIAGRAM.

Quadruple Riveted Joint A2 Plate 17 in. × 0·58 in.
Hydraulically Riveted with 20—$\frac{7}{8}$ in. Steel Rivets.
Snap Heads and Points.

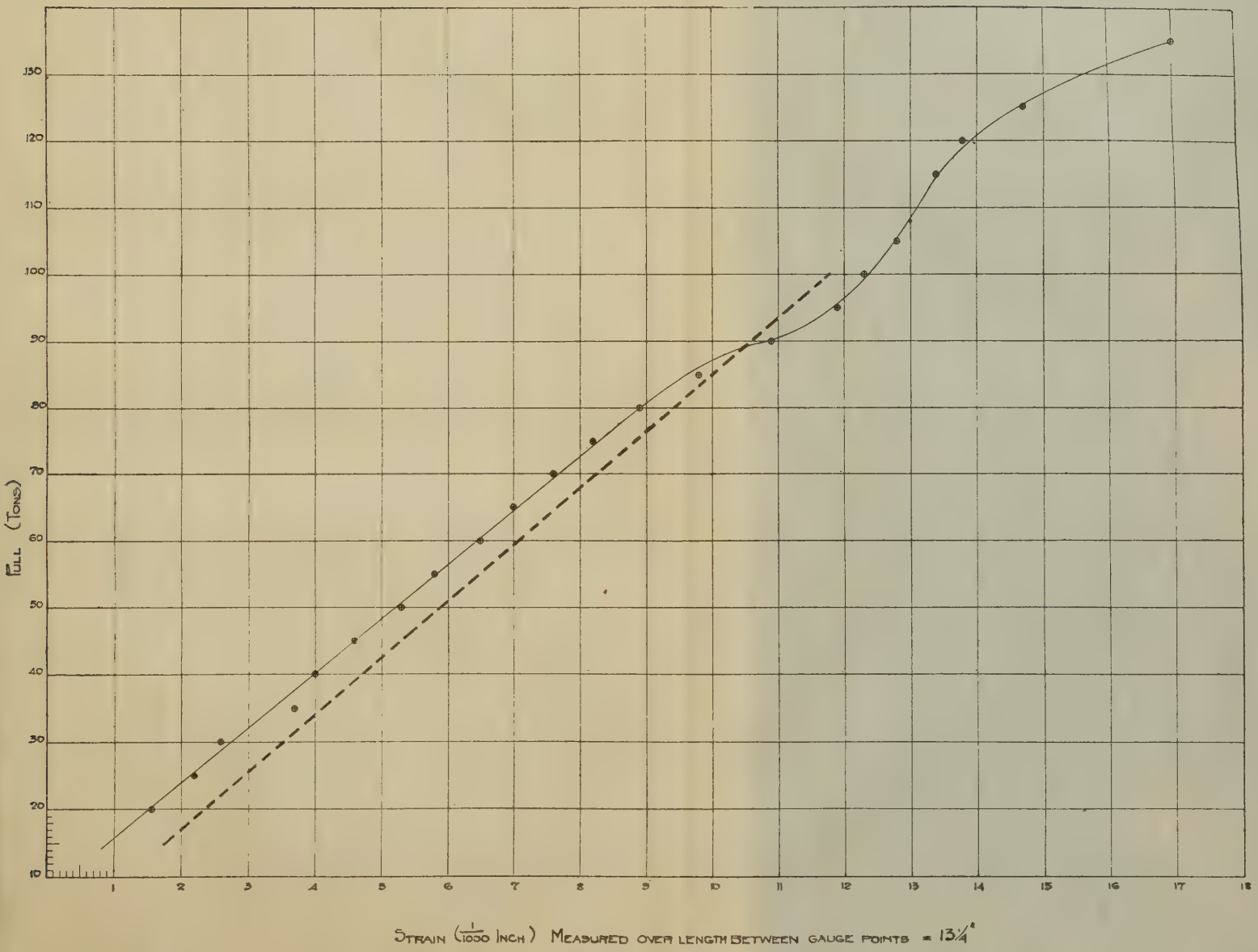


Fig. 10.

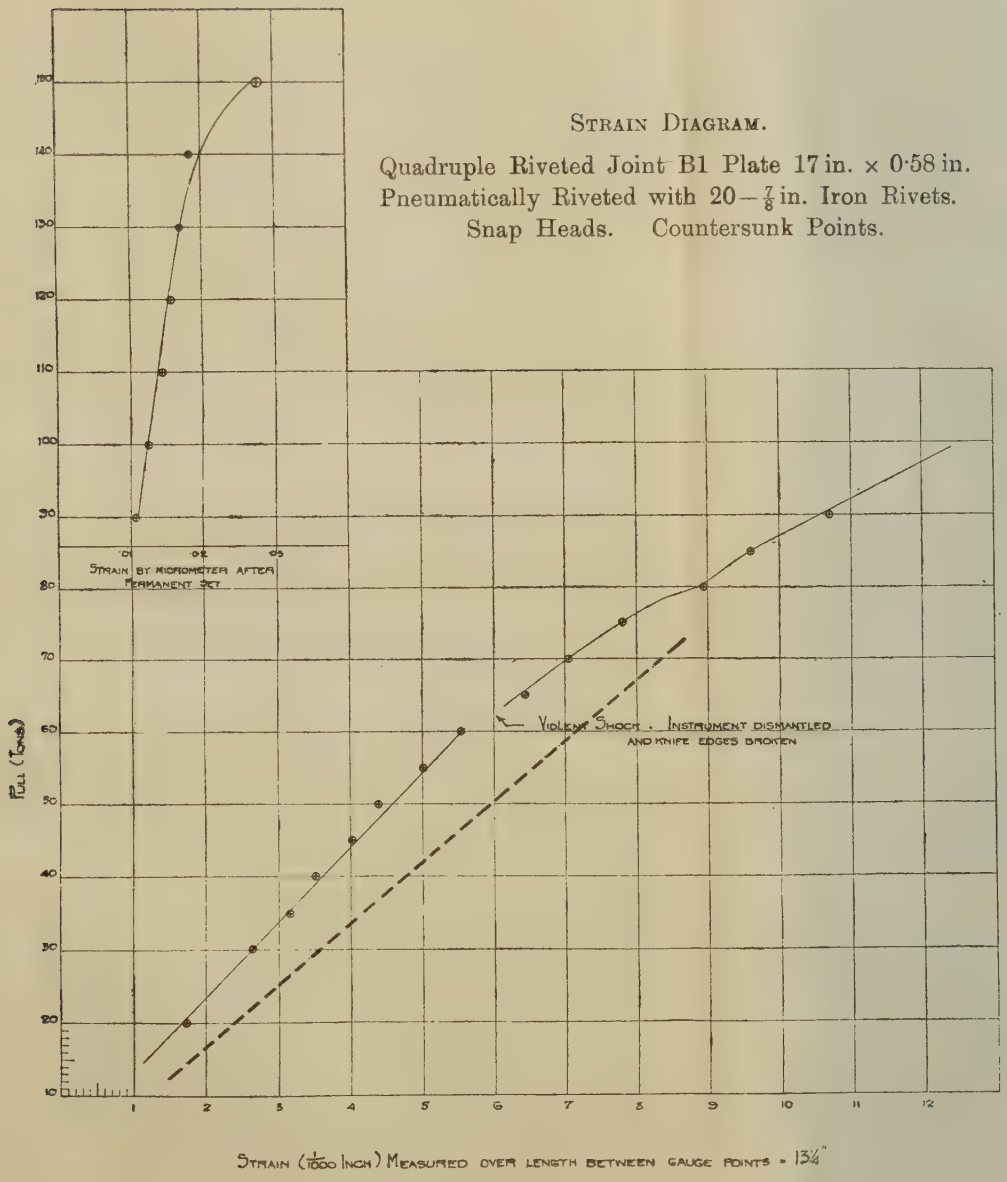

STRAIN DIAGRAM.
Quadruple Riveted Joint B1 Plate 17 in. × 0·58 in.
Pneumatically Riveted with 20—⅞ in. Iron Rivets.
Snap Heads. Countersunk Points.
STRAIN BY MICROMETER AFTER PERMANENT SET
VIOLENT SHOCK - INSTRUMENT DISMANTLED AND KNIFE EDGES BROKEN
PULL (TONS)
STRAIN (1/1000 INCH) MEASURED OVER LENGTH BETWEEN GAUGE POINTS = 13¼"

Fig. 11.

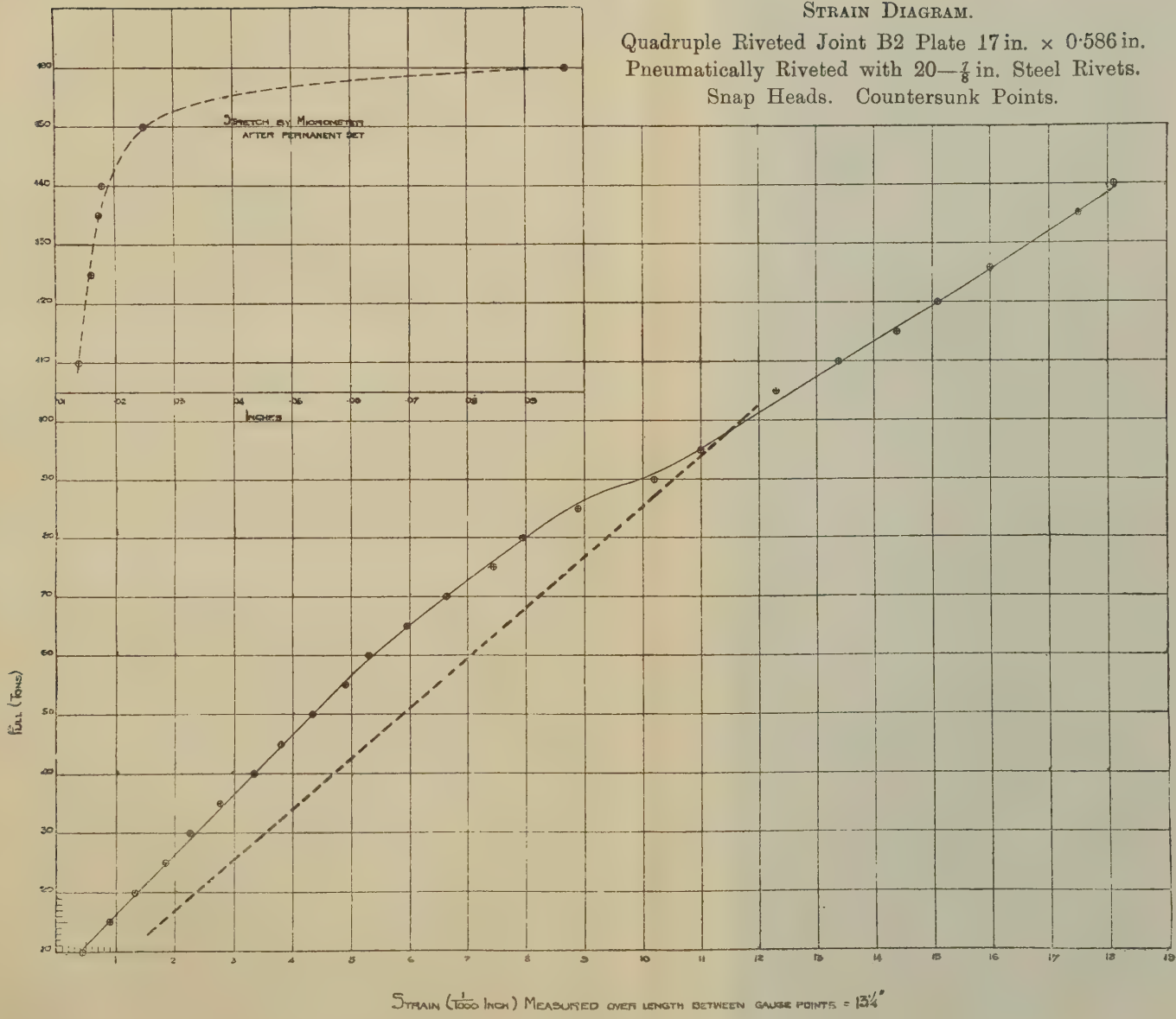

STRAIN DIAGRAM.
Quadruple Riveted Joint B2 Plate 17 in. × 0·586 in.
Pneumatically Riveted with 20—7/8 in. Steel Rivets.
Snap Heads. Countersunk Points.
SKETCH BY MICROMETER AFTER PERMANENT SET
INCHES
FULL (TONS)
STRAIN (1/1000 INCH) MEASURED OVER LENGTH BETWEEN GAUGE POINTS = 13¼"

Fig. 12.

STRAIN DIAGRAM.

Quadruple Riveted Joint C1 Plate 17 in. × 0·59 in.
Hand Riveted with 20—$\frac{7}{8}$ in. Iron Rivets.
Pan Heads. Countersunk Points.

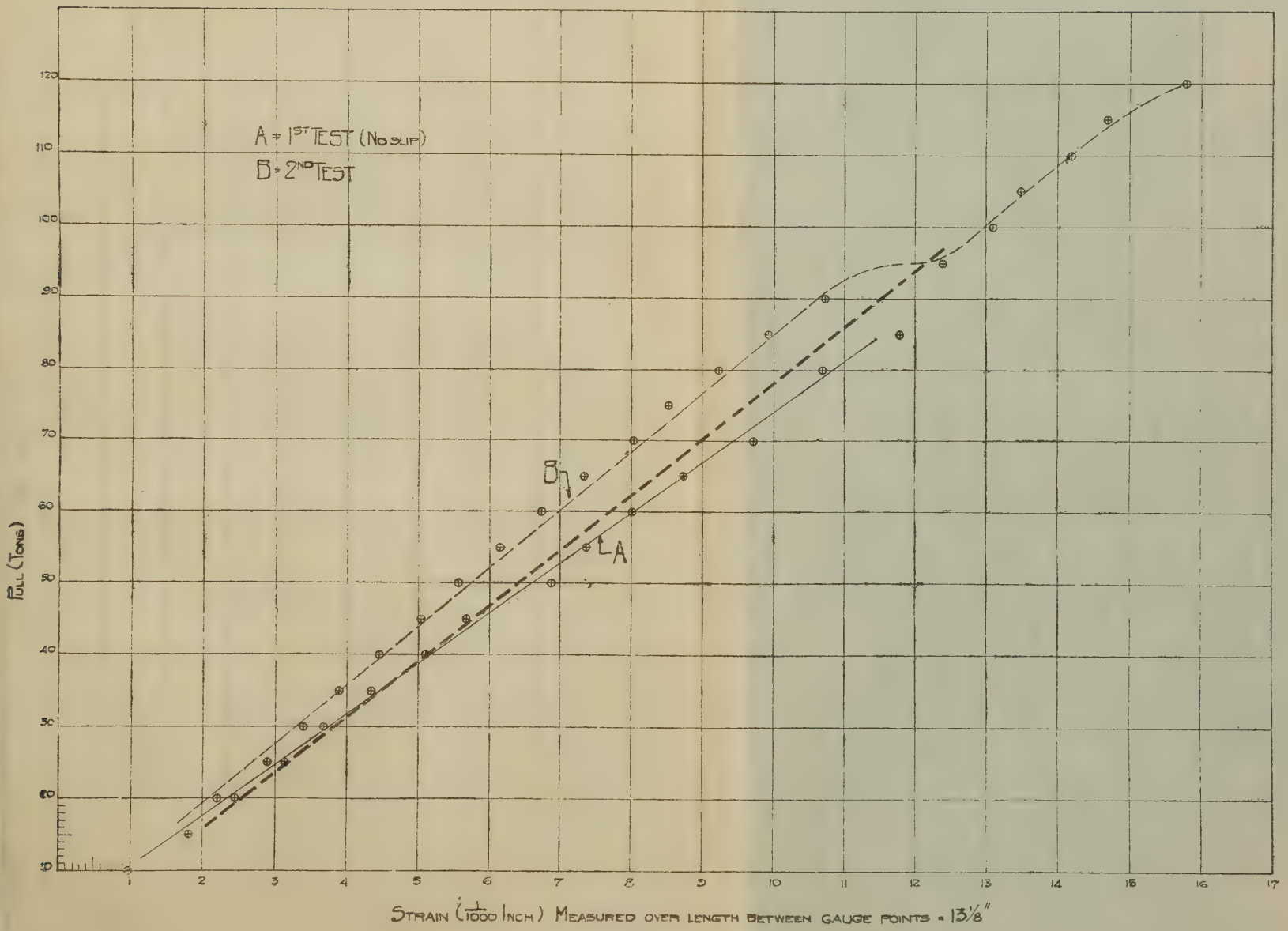


Fig. 13.

STRAIN DIAGRAM.

Quadruple Riveted Joint C2 Plate 17 in. × 0·59 in.
Hand Riveted with *15—$\frac{7}{8}$ in. Steel Rivets.
Pan Heads. Countersunk Points.

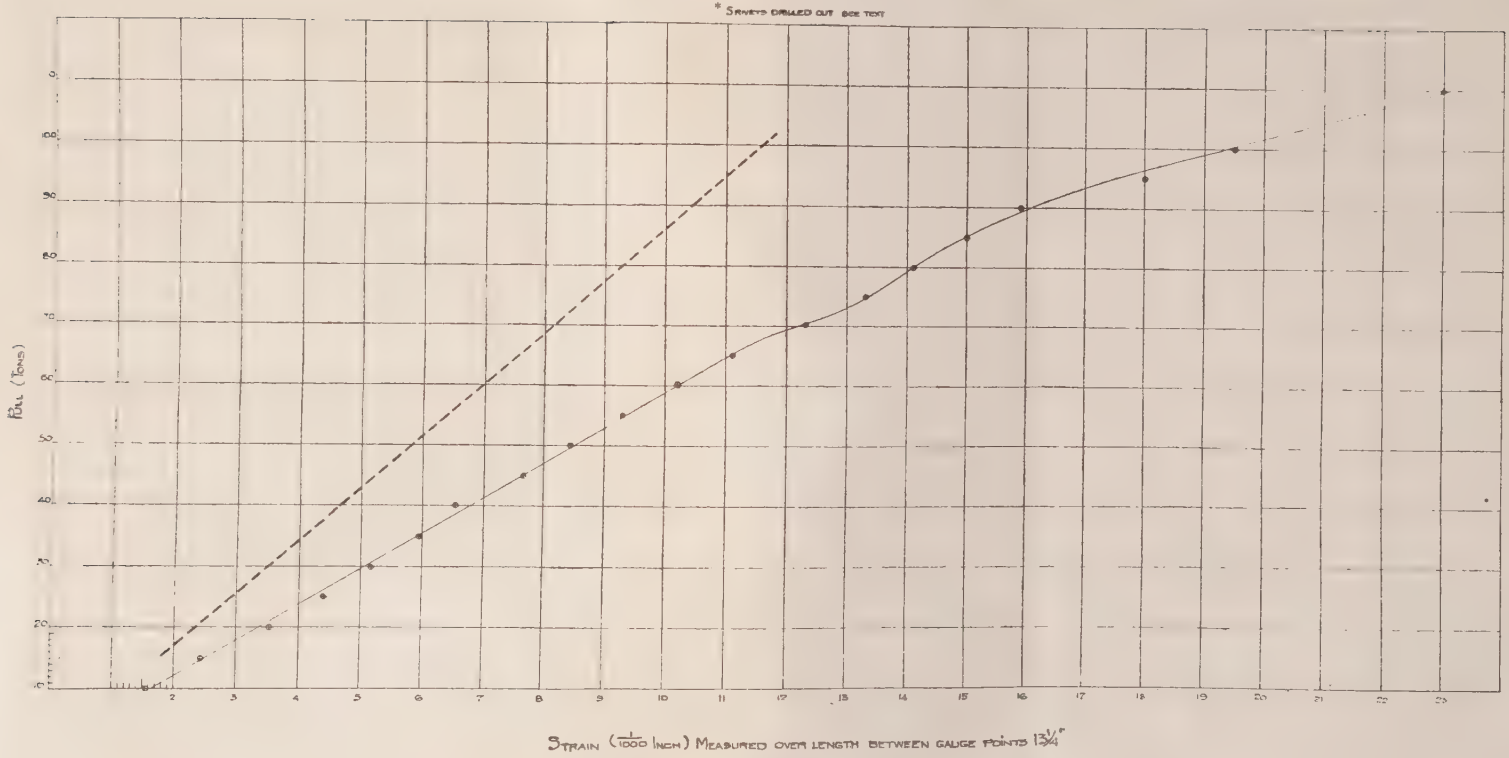


Fig. 14.

ascertained moduli of the material of the plates. It will be observed that the stretch represented by this line corresponds approximately with the average stretch across the *thickness* of the plate in the position shown.

The same process was followed with some of the treble-riveted joints, viz., A1, A2, and B2, with the same results. Fig. 6 shows the strain corresponding with various positions of the strainmeter, as indicated on the diagram. In this case, however, a succession of readings was taken *across* the plate in order to demonstrate that the pull was uniformly distributed. The thick dotted line in this case also shows the strain that would occur in the normal material when exposed to the pulls applied to the joint, and, as will be seen, this stretch corresponds approximately with the average stress over the thickness of the plate.

From the results of these observations it appears that the transference of pull from one plate to the other, together with the effect of bending, leads to a concentration of stress at the points marked A A in the sketch shown on the blackboard, and to a corresponding relief of stress at the points marked B B.

In applying these results to the case of similar joints, in the shell plating, say, of a cargo vessel, it is necessary to remember that the joints in the actual vessel are subject to some lateral restraint by reason of the plating above and below them. It is also necessary to remember, however, that the factors which produce this wide variation of stress are present in the butt of the actual vessel, although the consequences of such concentration of stress are mitigated somewhat before the critical point is reached by a certain amount of elastic accommodation in the joint itself.

In carrying out the experiments one or two points were observed which seemed to throw some light on the distribution of load amongst the rivets. It will be observed that the ends of the plates were securely bolted to the holders which were attached to the proving machine, and that consequently there was formed there a lapped joint secured by bolts. In

all cases it was noticed that the bolt holes in the plates along the line A, Figs. 4, 17, and 18, were very much distorted after the full power of the machine had been exerted. This distortion was less pronounced in row B, and decreased gradually; the holes in rows D and E were quite circular. The eccentricity of the holes in row A, however, was very pronounced, and could be measured easily by means of an ordinary scale. It was also seen that in the riveted attachment itself the outside rows of rivets seemed to be more severely stressed than the inner rows, and this was clearly seen in the fractured plates, and also in those which were upon the point of rupture. In the opinion of the writer this is due to the variation in stress found in the two plates in the vicinity of the outside rows of rivets. The connection between the variation of stress in the joint and the proportion of load carried by the rivets is no doubt exceedingly complicated, but it is certain that the force transmitted is not distributed equally amongst the rivets. Accepting the assumptions underlying the theory of riveted joints a stronger connection can be produced by spacing the rivets more widely in the outer rows than in the inner. This undoubtedly leads to a stronger joint at the point of rupture, but it also implies a more unequal distribution of stress in the plating of the joint in the vicinity of those rows of rivets. In determining the disposition of the rivets in a butt or lapped joint it should be remembered that wide differences in states of stress are encountered at different points, that the rivets do not share equally the burden of transmitting the load, and that the efficiency of the joint when performing the most important part of its work—that is, up to the slip point—appears to depend upon the number of rivets associated with a uniform spacing.

Figs. 5 to 14 inclusive show diagrams of strain measured over the whole joint. In the case of the treble-riveted specimens the distance over which the strain was measured was approximately $11\frac{1}{2}$ inches; in the case of the quadruple speci-

Fig. 4.—Five Rivets Drilled Out Before Using.

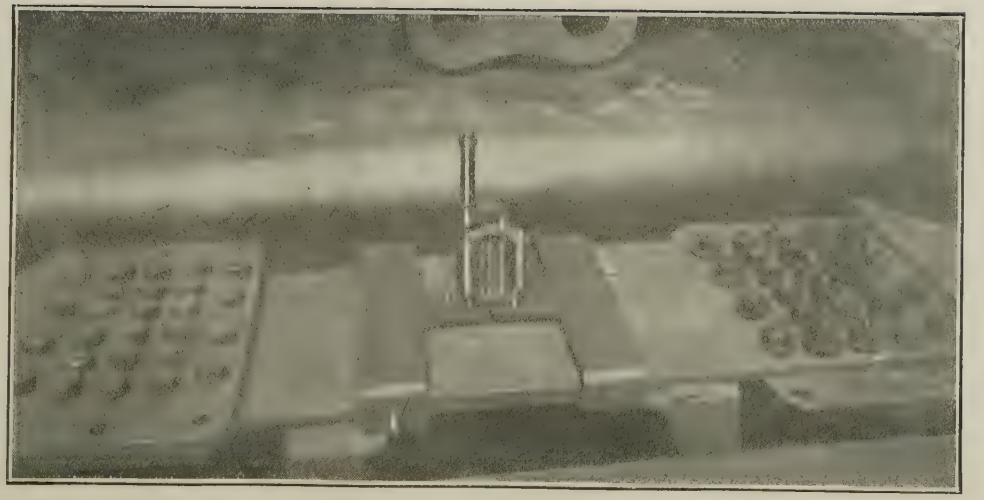


Fig. 15.—Strainmeter in Position.

Fig. 16.—Method of taking Observations.

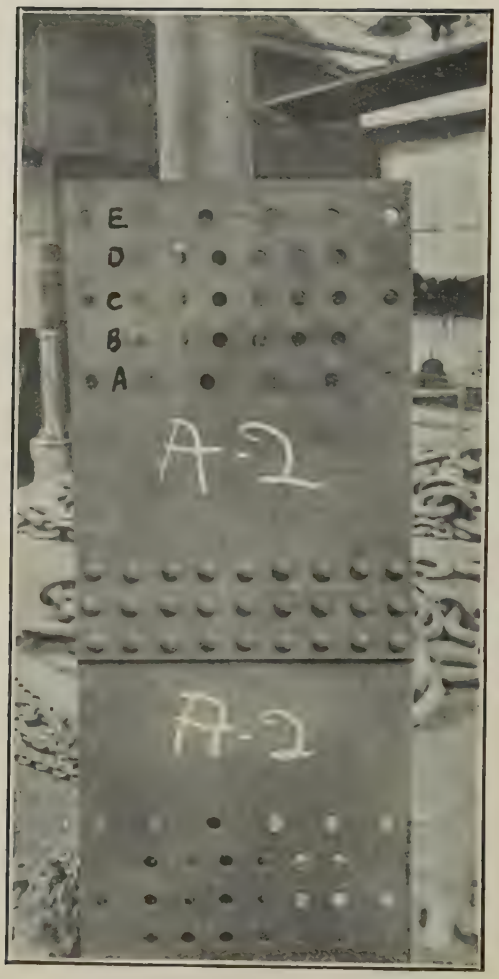


Fig. 17.—Showing Elongation of Bolt Holes.

Fig. 18.—Showing Elongation of Bolt Holes.

Fig. 19.—Joint on Point of Fracture.

Fig. 20.—Joint on Point of Fracture. Note Rivets in Outer Row.

Fig. 21.—Showing Typical Fracture. The Plate did not break through the Line of Countersunk Holes.

mens it was approximately 13¼ inches. The thick dotted line on each diagram shows the strain which would take place in the normal plate over the same length, and for the same stresses, calculated from the ascertained moduli of the plates. It will be seen that, with the exception of A1, the former correspond fairly closely with the latter. In the case of specimen A1 the nature of the graph near the origin suggests that some lack of symmetry may have existed.

It is considered that the results of this research may be stated as follow:—

(1) The assumptions underlying the theory on which the design of riveted joints rests are not valid, *i.e.*, the load is not distributed evenly among the rivets, and no uniform state of stress exists anywhere in the joint.

(2) For pulls up to the point at which slip takes place the maximum stress occurs in each plate on the surface next the edge of the joint. At this point the stress is nearly double the stress in the normal plate. On the opposite surface the material is practically relieved of stress. The average stress across the thickness of the plate is, therefore, approximately the same as that found in the normal plate.

(3) Slip takes place in the joint when the pull applied, distributed over the area of the rivets, produces a stress figure of from 7·5 to 8·0 tons per square inch. Up to that point the joint behaves as an elastic solid. After an interval the joint recovers its power of adhesion, and gives a similar result, on retesting, to that already obtained.

(4) The pull producing slip, when referred to the sectional area of the normal plate, and to the area of

the material between a line of frame rivets spaced seven diameters apart, corresponds with a mean stress of 9·0 tons per square inch, and 11·0 tons per square inch respectively.

(5) No appreciable distinction can be drawn in regard to the elastic qualities or ultimate strength of the joint in respect of the method of riveting employed, or the rivet material used.

(6) The average strain measured over the whole joint does not materially differ from that found in the surrounding material.

(7) In a lapped joint the rivets in the outer rows are more severely stressed than those in the inner rows.

The writer desires to express his indebtedness to Mr. Dickinson, of Messrs. Harland & Wolff, Govan, for the assistance he received from him in the preparation of the samples experimented upon.

Discussion.

Dr. T. Blackwood Murray (President): This is a very exhaustive paper on the strength of riveted joints, a subject of great interest to every engineer. The facilities at Dr. Montgomerie's command have enabled him to carry out tests to destruction on actual every-day instances of riveted joints. The history of the failure of the joints has been carefully noted and the results graphically described. The paper, therefore, embodies an immense amount of useful information, and appears to me to form a very interesting context to the paper which we had earlier in the session from Prof. Coker on the effect of circular holes on the distribution of stress in tension members. Both these papers deal with what might be termed very elementary structures in engineering; but they illustrate how

Dr. T. Blackwood Murray.

necessary it is that experimental work, and actual tests, should be made at every stage wherever possible in the design of a mechanism, so that we may correct and adjust our theories concerning the strength of structures. Too often in the past, when failures of structures occurred, which under the ordinary theory used still showed a margin of safety when subjected to stress, and therefore were apparently sufficiently strong, people scoffed at theory, and pointed the finger of scorn at the designer, whereas the real error lay in the fact that the theory used had been crude and did not take cognisance of the fact that, instead of being uniformly stressed at the mean average, the distribution of stress in given parts might vary to very wide limits, and that failures might, therefore, occur at one part of the member long before the danger zone had even been approached in other parts.

Prof. Coker gives a very simple practical rule for estimating the maximum stress in a tension member, and shows that in ordinary structural members the maximum stress may be from two to three times the mean stress; and it is very interesting to note that in Dr. Montgomerie's summing up he states: "At this point the stress is nearly double the stress in the normal plate." To put it another way, the designer, assuming equal distribution of stress, might imagine he had a margin of safety of 6, whereas Prof. Coker and Dr. Montgomerie both show that the real factor of safety is somewhere between 2 and 3. Now it appears to me that both these papers are very valuable to the engineer, as they demonstrate quite clearly what the ultimate strength of a member is, and from this experimental data we can revise our formula accordingly, and employ a suitable factor to compensate for the unequal distribution of stress, and then, knowing the ultimate strength, we can add whatever actual factor of safety we consider the occasion demands. I think papers like these show how extremely complex the theory of simple structures is, and what an enormous amount of experimental work lies in front of the engineer before he can

Dr. T. Blackwood Murray.

with certainty prophesy how, in what manner, and at what particular stress any given structure will fail. We are very much indebted for this very exhaustive investigation that has been carried out by Dr. Montgomerie.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member): I propose making but a small contribution to the discussion on this paper. My object is to call attention to a difference between the usual shipyard butt and the one forming the subject of the experiments, and to ask a question.

A very usual practice in shipbuilding is to form the butt as in Fig. 22. The portion above the dotted line is planed away for the breadth of the lap of the adjoining strakes, in order that they may lie fairly over the butt and form a water-tight

Fig. 22.

joint without the addition of the tapered liners which would otherwise be necessary.

Had the test specimens been made in this way, omitting, of course, the chamfering, no doubt the stress distribution in the unpierced parts of the plate would have been much more uniform than was the case in the actual ones tested; for in the test specimens each unpierced portion of the plate is in the condition of a tension member with an asymmetrical load, naturally giving rise to a varying stress distribution over the thickness of the plate; whilst in the case sketched above the loading (in these parts) would be quite symmetrical with consequent stress distribution over the thickness.

I would ask Dr. Montgomerie to tell us if, in his opinion, any marked difference would have been shown in his general results had the specimens conformed to regular shipyard practice in the manner indicated?

Mr. George Nicol.

Mr. George Nicol (Member): It is pretty well admitted that the theory on which the usual rules for determining the number of rivets required in an ordinary joint or ship plating is not based on a sound foundation. At the best, it is a convenient method of arriving at the information required, and must be used with the judgment born of experience. The general practice of making the rivets of such a number that their aggregate shearing strength approximates to the tensile strength of the plate between the rivets, has been found to lead to safe construction; but it is understood, as pointed out by Dr. Montgomerie, that the total force transmitted by the joint is by no means equally distributed amongst the rivets, and this is shown in the stress-strain diagram in the paper. It is important to note that up to the slip point the joint acts as an integral part of an elastic solid. Thus the frictional resistance of the surfaces in contact is sufficient to meet the stress up to this point, and as this stress usually exceeds that allowed to come on ship structures, the shearing strength of the rivets is not called upon at all. It is undoubtedly due to this that ships maintain their tautness.

The experiments clearly show that when the riveting work is of good quality it is immaterial, in stresses at least up to the slip point, whether the rivets be clinched by hand or by machinery, and this in my opinion might be expected, since it is the binding force between the plates, due to the contraction of the rivets when cooling, rather than to the manner of clinching them, which creates the frictional resistance. Dr. Montgomerie draws attention to the fact that the bolt holes through the plate and the holder of the proving machine in the line nearest the joint, were very much distorted after the full power of the machine had been exerted, and that the distortion was less in the rows of holes furthest from the joint. It was also seen that in the riveted attachment itself the outside rows of rivets were more seriously stressed than the inner rows. Dr. Montgomerie accounts for this by

Mr. George Nicol.
the variation of stress found in the two plates in the vicinity of the outside rows of rivets. He does not, however, state a reason for this variation in stress. Clearly, it must be due to the bending tendency introduced at these places by the step in the line of action of the applied force. He brings out an interesting point where he shows that up to the point at which slip takes place the stress on the surface next the joint is nearly double the average stress in the plate, while it is practically *nil* on the opposite surface, showing the wide variation of stress across the thickness of the plate. In paragraph 3, page 297, it is stated that a joint stressed to the slipping point after an interval completely recovers its power of adhesion. I am rather surprised at this, as I thought it was generally understood that when frictional resistance of a joint is once destroyed any further stressing of the joint had to be borne directly by the strength of the rivets.

Mr. T. A. Hayward (Member): The assumption that in a lap joint all the rivets are in equal stress has been proved by Dr. Montgomerie's experiments to be fallacious, and one cannot help feeling that improvements may be made in the existing rules for regulating the spacing and number of rivets in a lap joint. I agree with Dr. Montgomerie that further experiments should be made to acquire additional information on this point. To ascertain the advantage of quadruple over treble riveting, would it not have been better to have made three of the sample joints between plates of 23½ inches broad and 0·44 inch thick with treble riveting, and the other three with quadruple riveting? Treating in like manner also the joints in the plates 17 inches in breadth and 0.58 inches in thickness. This would doubtless have furnished more positive information than in the case of the sample, Fig. 4, where five of the rivets were drilled out of the joint.

I am not willing to accept without further experiment the conclusion that "No appreciable difference can be drawn in regard to the elastic qualities or ultimate strength of the joint in respect

of the method of riveting employed, or the rivet material used." The joints A1 and A2 were hydraulically riveted, and the rivets had snap heads and points. The power applied to the rivets was 40 tons. The other specimen joints were pneumatically riveted and hand riveted respectively. The power to produce slip in each case did not appreciably differ. Nevertheless, one would like to have seen all the rivet heads and points made alike, so as to decide definitely which was really the best system. It has been generally understood that hydraulic power, assuming it to be practicable, is the best for riveting ship plates. The reason is due to the fact that the full power is available throughout the stroke of the riveter, and if the power exerted is sufficient, it will stave the rivet until the hole is completely filled before the head is formed. In the case of either pneumatic or hand riveting the head begins to be formed as soon as the percussion blows are applied, and if the rivet is comparatively long it is not staved right through its length. It will be observed that the powers for slip and ultimate stresses were less in the specimens which had been riveted by pneumatic power, while those riveted by hand were practically equal to those hydraulically riveted. The reason for this is that the blow imparted by the hand hammer is greater than that of the pneumatic hammer, and a longer time is taken to close the rivet than in each of the other processes, the blows being continued until the rivet is much colder and becomes black. It is usually the case also that when hand riveters have driven up a succeeding rivet, they return to the previous one when it is practically cold and hammer it again with plying hammers. If the same time were allowed for hydraulic riveting a far better result would accrue, because the "holding on" of the riveter until the rivet is cold ensures that the rivet will retain the compression after the riveter is released. This is a most important point, and all riveters should be fitted with an automatic time-holding arrangement.

Another important point is to employ the right power when closing each size of rivet. From Dr. Montgomerie's experi-

Mr. T. A. Hayward.
ments it is apparent that this aspect of the question deserves greater attention. If sufficient power be applied to hydraulic riveting, the plates can be compressed and held together so that there will be no slip until the ultimate stresses are reached Assuming that to be the case, it seems probable that treble riveting can be made as effective as quadruple riveting. The suggestion, therefore, arises that the middle row of rivets should be spaced as close as possible, while the spacing in the outer rows should be widened and the rivets made of larger diameter. These experiments demonstrate to the shipbuilder that the rules for riveting now in use are ample to secure stability of structure, but do they not also show an excess over absolute requirements? The method of testing used in the joints does not obtain with ship plates in actual practice. The fracture of the plates was in all cases through the first line of rivet holes, which was undoubtedly due to bending action. In the strain diagram, Fig. 5, while one side of the plate showed excessive tension, the other side was actually shown to be under compression—that the material on one side of the neutral axis was alone subjected to the strain. As ship shell plates are not only subjected to tensile but also to compressive stresses, it seems absolutely necessary to provide against slip, because if slip does take place in the one direction it will in all probability do so in the other. This leads me to emphasise the necessity for further experimenting. It is a well-known fact that mild steel of the right quality, by subjecting it to strains in various directions which causes the material to flow will add materially to its strength.

Two plates, each $\frac{1}{2}$ inch thick, were put together, and four $\frac{13}{16}$-inch holes drilled through them, into which four $\frac{3}{4}$-inch diameter rivets were closed under varying hydraulic powers of 25 tons, 50 tons, 75 tons, and 100 tons respectively, Fig. 23. The rivet compressed with 25 tons pressure just filled the hole; with 50 tons pressure the rivet heads were compressed together $\frac{1}{32}$ inch, and the body of the rivet increased in diameter

at the middle from $\frac{26}{32}$ inch to $\frac{27}{32}$ inch; with 75 tons pressure the heads were compressed together $\frac{1}{16}$ inch, and the body of the rivet increased in diameter $\frac{1}{16}$ inch at the middle; and with 100

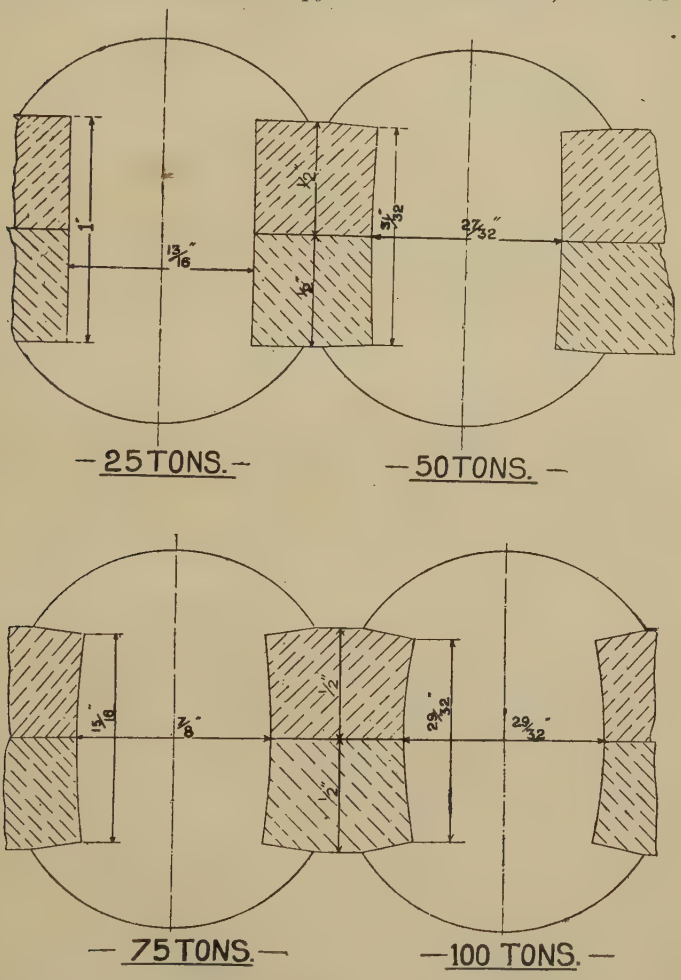


Fig. 23.

tons pressure the heads were compressed together $\frac{3}{32}$ inch, and the body of the rivet increased in diameter at the middle by

Mr. T. A. Hayward.

$\frac{3}{32}$ inch. It has been observed when riveting that the hydraulically closed head has protruded outside the riveter snap, thus leaving too much material in the head, while inside the holes the material has not been fully staved, indicating the effect upon a rivet which has been closed with too little power and while it is too hot. The effect of closing a rivet absolutely cold is to reverse the result, by staving more material into the hole, and leaving the riveter snap only partially filled. Rivets should be hydraulically closed at blood red heat.

Mr. William Thomson, B.Sc. (Member): Despite the important part played by riveted joints in all forms of structural engineering, our knowledge of the actual stresses existing in such joints is very meagre, and the results of Dr. Montgomerie's experiments have a special value in enabling us to form a quantitative idea regarding the very complex stresses in a riveted connection. The first part of the experimental work is directed to the determination of the point at which frictional slip occurs, and this is found to take place at a stress of 9 tons per square inch of sectional area of the normal plate, a figure which compares with $7\frac{1}{2}$ tons per square inch shown by the results of the tests carried out by the German Admiralty some years ago. It is strange that the very important part played by the frictional resistance is almost entirely neglected in treatises dealing with riveting, many pages being devoted to the theoretical determination of rivet spacing, very often based on entirely erroneous assumptions, one of the most important of which, namely, that the load is distributed evenly among the rivets, is shown in this paper to be very wide of the mark.

The stress at which slip occurs is somewhat higher than the calculated stress which would be considered satisfactory for a ship, and, as calculated stresses are but rarely experienced in the lifetime of a vessel, it would appear that one of the principal functions of rivets is to simply bring the surfaces sufficiently close together to produce an interlocking action between them. From this I think it may be inferred that the best disposition of

rivets in a butt is to space them as evenly as possible, and not to attempt to attain compliance with a standard deduced purely from theory by adopting an irregular spacing. At the same time it is clear that the area of contact between the plates is a matter of some importance, and the author might state what bearing the experiments have on this factor. It would also have been very interesting if the observations of slip had been continued up to the point of fracture. I expect that after the point of slip had been passed, the shearing stress on the rivets would have been called into play, and the curve would have continued in a straight line until the elastic limit of the rivet material was reached, when another well-defined break would occur in the curve. Perhaps Dr. Montgomerie will say if any of his observations were extended in this direction.

The second portion of Dr. Montgomerie's work is devoted to the stresses in the material in the neighbourhood of the butt, and in this part of his paper he has struck virgin soil. It is quite apparent, on watching a lapped joint being pulled in a testing machine that stresses of considerable magnitude are developed in the material, and that these stresses are far from being uniformly distributed across the section. The experiments yield some very interesting results on this point, and, in particular, show that while the average strain over the material in the lap joint does not appreciably differ from that in the surrounding material, there exists in the vicinity of the beginning of the overlap a large variation of strain across the thickness of the plate, varying from zero on the surface of the plate away from the area of contact to twice the average strain near the area of contact.

It is clear that at two definite localities there exists a stretch which is practically double that found in the normal material, and the implications of this fact are very far reaching. It would appear to be indicated that an overlap joint is hardly capable, without permanent deformation, of supporting a load of much more than half that which would be borne by the unpierced

Mr. William Thomson, B.Sc.

material. In an actual structure this, of course, leads to the result that the joint does not transmit its proper share of the load, which leads to an increase in stress in the surrounding material, but this augmentation is small, and is not likely to be a matter of any consequence. The results of the experiments, as a whole, confirm the impression that overlap butts as ordinarily fitted are strong enough to meet all reasonable calls upon them; while the data regarding the actual point at which slip takes place will be of very considerable value to a designer who is faced with exceptional stresses or novel conditions of design.

Mr. G. R. Edgar, B.Sc. (Member): The value of the slip stress is of primary importance, and though, of course, it has been apparent that it was greater than the working stress experienced on a vessel's structure, the evaluation of it for lapped joints imposes also a limit on the comparatively unknown actual values of these stresses. Apart from their value to research, the conclusions have a direct bearing on present riveting, and in this connection I should be glad if Dr. Montgomerie would give his opinion as to whether these results are strictly applicable to butt-strapped joints. The distribution of stress, as indicated on page 295, is what would naturally be expected, having regard to the bending of the joint increasing the tension due to the pull on one surface of the plate, and decreasing it on the other. In a double-strapped joint there would be no bending, and though a single-strapped joint, which I suppose would bend, might be regarded as a double application of a lapped joint, it is perhaps somewhat sanguine to say that the flow of stress and effect of its distribution on rivets and plates would be the same in these cases as for lapped joints.

The effect of cutting out rivets as carried out gives an indication of its bearing on the general results, and in light of the conclusions arrived at, the results of further experiment up to the slip point, with varying pitch of rivets in the rows, would be of interest. One small point which appears to be somewhat peculiar is the result obtained in Fig. 5 in respect of the stress

for the position F. Would not a contraction instead of an extension be that naturally expected transversely across the plate? I cannot refrain from saying that these experiments are only one example of the many similar investigations within the scope of the strainmeter used in this case, an instrument which, though a comparative babe may use it, is a masterpiece of accuracy and invention. Our best thanks are therefore due to the inventor, Dr. Montgomerie.

Dr. James Montgomerie: I think that Dr. Blackwood Murray has drawn attention to the most important feature revealed by these experiments, namely, that there exists a very decided variation of stress across the thickness of the plate. When he points out how extremely complex is the theory of simple structures, he draws attention to an important fact; our principal need in shipbuilding to-day is the knowledge which can be derived from experimental work. The application of the methods of the civil engineer to the problems connected with the strength of ships which confront the naval architect has been widely adopted in recent years. It has not perhaps been clearly realised that a great deal of experimental work must be done before the present methods and indiscriminate application of the formulæ of civil engineers to the complex structure of steel ships can be justified.

Mr. Riddlesworth's question is a pertinent one, and I have no hesitation in saying in answer to it that the type of butt given in his sketch would be less severely stressed than in the test specimens. At the same time, I am strongly of opinion that the variation of stress which the experiments revealed is much more the product of discontinuity than of the non-axial nature of the pull applied. The butt also as shown in the sketch introduces a few other features, the experimental examination of which might be valuable; for example, the adhesive properties of the joint and the effect of the inclination of the two surfaces.

The point which Mr. Nicol makes in regard to the variation

Dr. James Montgomerie.

of the load taken by the different rows of rivets is an interesting one, especially as the phenomenon was seen not only in the joint itself, but also in the holders. I do not think that the bending-moment which exists across the joint is primarily responsible for the facts observed. I believe they can be simply explained by a consideration of the manner in which the stress, however produced, is transferred from one plate to the other. This transference of stress is naturally most pronounced in the vicinity of the outer rows, and consequently the stress across the rivets in the outer rows is greater than that in way of the inner. It is this fact which appears to indicate that a variation in the spacing of the rivets is a refinement which produces no real increase in the strength or efficiency of the joint.

There are one or two of Mr. T. A. Hayward's remarks which I am not able to accept. For example, with regard to the conclusion arrived at that no appreciable difference can be drawn in regard to the elastic qualities or ultimate strength of the joint in respect of the method of riveting employed, or the rivet material used, I may say that these experiments were commenced with a preconceived, and therefore unscientific, idea, that hydraulically riveted joints would prove superior to those riveted by hand. It is the duty of the investigator, however, to accept facts, and the results of these experiments, taken as a whole, conclusively show that no sensible distinction can be drawn between the three methods of riveting "when each is properly performed." At the same time there is another consideration which is probably at the root of Mr. Hayward's inability to receive the conclusion above stated, and that is, that in the ordinary course of shipyard practice it would be easier to secure consistently good results from a system of hydraulic riveting than from a system of hand riveting. If that is what Mr Hayward means, I agree with him. Mr. Hayward also states that the method of testing used in the joints does not obtain with ship plates in actual practice. If he will have the goodness to refer to my paper

Dr. James Montgomerie.

he will find that I deal with this point. The only sensible difference which exists between the joints in the actual vessel and those in the Kinning Park Proving House is that the former are subject to some lateral restraint by reason of the plating above and below them. It is also necessary to remember, however, that the features which produce a wide variation of stress, the principal of which is the element of discontinuity, are present in the vessel and must be considered. Mr. Hayward also appears to think that some improvement can be made in the efficiency of the joint by a redistribution of the spacing and diameter of the rivets. I am not in agreement with this. The idea for these variations sprung naturally from the premises on which the theory of riveted joints was founded. These premises can no longer be accepted. I am strongly of the opinion that, having regard to all the features inherent in this most complex problem, the best shipbuilding joint is produced in large plates by the uniform spacing of rivets. In my opinion also the task of the designer is first to ascertain the number of rivets which will produce in the joint the qualities of an elastic solid up to a certain stress, and then space that number of rivets in such a manner as to secure uniform adhesion over the two surfaces.

In regard to the point made by Mr. Thomson as to the bearing of the experiments on the area of contact between the plates, I think it would be difficult to deduce any general relation, and the interdependence of the number and size of the rivets, the area of the surfaces in contact, and the point at which slip takes place, might very profitably form the subject of a further series of experiments. With regard also to the observations of slip continued up to the point of fracture, it is to be said that this was found almost impossible to obtain with an accuracy corresponding to that obtained for lower loads. So far as could be seen, the strain found beyond the slip point was such as to correspond in form with the strain diagram of the solid plate after the yield point had been passed.

Dr. James Montgomerie.

Concerning Mr. Edgar's question as to whether the results are strictly applicable to butt strap joints, I would say that in my opinion they are not strictly applicable. As Mr. Edgar observes, the element of bending is not present in the latter type of joint, but the element of discontinuity is perhaps a little accentuated. After having carefully observed the behaviour of the strainmeter as the loads were applied, and particularly when small loads were applied, I came to the conclusion that the discontinuous nature of the joint was responsible for the greater part of the variation in stress found, and I am strongly of opinion that designers would do well to pay considerably more attention to this feature than has been paid to it in the past.

HIGH-SPEED CRAFT DURING THE WAR.

By W. W. Marriner (Member).

20th April, 1920.

To be able to move quickly, apart from its utility, has always a charm, and the advantages of high speed in warfare are so evident that it is hardly necessary to emphasise them. A higher speed than that of the enemy gives the advantage of position, and also the power of accepting battle or not, so that full advantage may be taken of any superiority in armament, or if the enemy has the more powerful weapons it is possible to keep out of his way.

Speed, however, cannot be obtained without paying the price, and whether it is the rate at which one lives, or the speed of an express train, or the speed of a vessel, in every case something has to be sacrificed in order to obtain what is desired. The amount of energy at our disposal is limited, and if we want to move quickly we must reduce the resistance to a minimum and utilise the maximum energy.

I have had the honour of being associated with Messrs. Yarrow during the whole of my career, and consequently my description in this paper of high-speed vessels is limited to what has been accomplished by this firm. I am quite sure that Sir Alfred Yarrow and Mr. Yarrow would be the very last to refuse a tribute to what has been done by other firms and individuals in the development of high-speed vessels.

One of the most renowned firms in this country is that of Messrs. Thornycroft, and the development of high-speed vessels owes much to the bold advances which have been successfully made by that firm from time to time, both in design

and in the taking advantage of the best available materials. Not only did they build many high-speed destroyers during the war, but they evolved a most successful high-speed coastal motor-boat. The feats accomplished by these coastal motor-boats are among the most remarkable of the war. Any results which may have been obtained by them are, in the first instance, due to the skill and endurance of the officers and men of the navy, but Messrs. Thornycroft deserve the highest praise for designing and building such wonderful craft.

Mention might also be made of the splendid work done in the early days by M. Normand the great French designer, our friend and rival. As an instance of business chivalry it might be of interest to you to relate an incident which happened many years ago when rivals were struggling to be the first to obtain 30 knots, and in the end it came to a neck and neck race between the firms of Normand and Yarrow. The Yarrow boat was finished first, and on trial obtained the coveted speed of 30 knots. Concerning this performance the first congratulatory telegram received by Messrs. Yarrow was from M. Normand, and it is a telegram which we prize more than any other received at the time.

The title of the paper is "High-Speed Craft During the War," and this enables me to draw attention to the splendid work done by passenger vessels, by high-speed steam yachts, by racing vessels of all kinds, and by hydroplanes, and it will be agreed that the lessons learned in some of these sporting vessels have advanced our knowledge in a most useful way.

In acknowledging the magnificent work which has been achieved by other builders of destroyers, the workers in science, and the pioneers in the various fields of industry, such as steel-makers, makers of turbines, and makers of auxiliary machinery, should not be forgotten, all of whom have contributed to making high speeds possible.

In the design of a high-speed vessel it is necessary to make a careful study of the conditions under which she has to operate.

A vessel for a shallow river is quite a different proposition from a vessel operating at sea, and again a high-speed vessel which has to operate on a short radius of action is very different from one which has to operate at a great distance from its base. The governing principle, however, remains the same, namely, resistance must be reduced to a minimum and power must be obtained most efficiently.

Consider, first of all, the question of weight, which is a large factor in resistance. It may be divided into weight of hull, weight of machinery, weight of crew and armament, and weight of fuel. The weight of armament is fixed by the Military Authorities (especially those of the enemy) as it is useless to get into a position to strike a blow, unless on arrival the blow can be made effective.

The total weight is largely influenced by the all important consideration of cost. Having determined the total displacement it is then possible to allocate what weight can be allowed for the hull and for the machinery respectively. If the vessel has only to make short raids and return immediately to her base, then it is obvious that the scantlings of the hull and the accommodation for the crew can be reduced, because the vessel can choose the weather in which she puts to sea, and the crew can put up with a fair amount of hardship for a short period.

In the late war the Germans made full use of this condition, and their destroyers used to put to sea with a minimum of fuel and outfit on board, with the consequence that in many cases they were able to outdistance British vessels which had naturally to be prepared for keeping the sea for an indefinite period in all kinds of weather.

Generally speaking, in the modern destroyer the distribution of weights is approximately as follows:—

Weight of hull - - -	35	per cent.
Weight of machinery - -	35	,,
Weight of armament and stores	7	,,
Weight of fuel - - -	23	,,

Having settled the weight which can be allowed for the hull, one can decide the dimensions of the vessel. For speed the important dimension is the length, for stability the important dimension is beam, and for strength the important dimension is depth. The length is, therefore, influenced by its relation to the beam and depth of the vessel, and it is here where the skill of the naval architect is shown by obtaining the very best compromise as regards the dimensions to be adopted, always keeping in view the special service for which the boat is to be employed. A vessel which has to be constantly employed with a fleet, and whose speed is determined by the senior officer of a larger ship, should be made stronger than the vessel which will only have to act independently or with vessels of its own class, when the senior officer of the flotilla is himself experiencing the shocks caused by waves. Even in a comparatively calm sea there is a certain speed for every vessel where the synchronism of the waves with pitching might become serious.

Much can be done by arranging weights relatively to the buoyancy at any part, so as to reduce the bending-moments, and present-day lightness in hull construction has been attained without any sacrifice of strength or decreasing the factor of safety, by a scientific study of the stresses involved and the best disposition of the material.

Having decided upon the dimensions of the vessel, the next important consideration is the form of the under-water hull, and in this connection tank eperiments are valuable; in fact, essential. One can hardly believe that 20 years ago it was necessary to go to Germany in order to have tank experiments carried out, although there were private tanks in this country which, however, were not available for public use. The form of the vessel is important not only from the point of view of reducing the resistance of the hull to a minimum, but also to ensure that the propeller works with the highest possible efficiency. From tank experiments it is possible to form a close estimate of the power required to drive the vessel, and for a given speed it is just as important not to overestimate the

power as it is not to underestimate it, because the weight of the machinery may be taken to be proportional to the power, and excessive weight of machinery means a load to be carried increasing also the weight of the hull, and thus doubly reducing the speed.

Possibly sufficient attention has not been paid to the underwater form from the point of view of obtaining the highest propeller efficiency, especially in vessels where the power is proportionately very large. It is well known that at high speeds the propeller is one of the most inefficient parts of the propelling installation. Models have been equipped with propellers driven by motors installed on the model and a measure taken of the power required by the motors. Naval architects in this country at one time would not place much reliance on results obtained in this way, but owing to the researches carried out by Mr. R. E. Froude at Haslar, and Mr. Baker at the William Froude National Tank, Teddington, means have been perfected by which accurate investigations can be made, and experience has proved that the methods adopted by them are sufficiently accurate to form a reliable guide. As long ago as 1903 Sir Alfred Yarrow advocated a flat-bottom stern for a destroyer in order to increase the propeller efficiency, and H.M.S. "Garry" may be looked upon as an early example of this type of stern for destroyers. The resistance of the hull is hardly affected as compared with the ordinary round-bottom stern, but the propeller efficiency is increased to a remarkable extent, a knot more speed being obtained for the same expenditure of power.

Having fixed on the weight of the hull and machinery, the designer is then in a position to say how much weight can be allowed for the armament and fuel on a vessel of certain displacement. The importance of weight on a modern destroyer may be illustrated by stating the fact that for every pound weight thrown overboard the vessel will be half an inch further ahead each hour, or for every ton weight saved half-a-length of the ship will be gained in an hour's race.

The relationship which exists between the various parts is one of the most important factors in the success of a destroyer, not only from the point of view of speed, but also from the point of view of seaworthiness. Any Government Department is in an unfavourable position in this respect as compared to a private firm, because in the latter there is one head who is in a position to settle what he considers to be the best compromise. Sometimes the hull has to be cut down, and sometimes the machinery, and sometimes it is necessary to say that the armament is not suitable for that particular size of vessel. In firms who make their own designs it has been noticed that every now and again a design is arrived at which gives results far ahead of what has been before obtained. For instance, in 1894, Sir Alfred Yarrow constructed the "Sokol" for the Russian Government which was a vessel 190 feet long by 18 feet 6 inches beam, with twin-screw engines of a total indicated horse-power of about 4,000 and Yarrow water-tube boilers. Her armament comprised one 75mm. gun, three 47mm. guns, and two deck torpedo tubes. She was the first vessel to attain a speed on trial of 30 knots, and this result was obtained principally by the adoption of water-tube boilers, and high-tensile steel in the construction of the hull. This special steel had a tensile strength of from 37 to 44 tons per square inch, and an extension of not less than 15 per cent. in 8 inches for plates $\frac{3}{16}$ inch thick. Its application permitted a reduction in thickness of 12 per cent. below that of the mild steel previously used, with such a saving in weight of hull that an extra knot was added to the speed. All the stanchions were made hollow, pressed steel was used wherever possible instead of cast metal, and for cabin fittings aluminium was adopted, all in order to save weight. She was built at the same time as other destroyers which had a difficulty in obtaining 26 knots.

The "Sokol" was gradually improved upon in future designs. Keeping as near as possible to the same relationship of weights and form, and taking advantage of every modern

improvement, what was considered one of the very best vessels they ever built, namely, the "Mode," was constructed in 1902 for the Swedish Government. She was 220 feet 3 inches long by 20 feet 6 inches beam, and had four Yarrow boilers, and twin-screw reciprocating engines of a total indicated horse-power of 6,400. The speed realised on the official trial was nearly 32·5 knots. For the size and power this was a remarkable result, especially as it was obtained when burning coal under the boilers.

The adoption of oil fuel was perhaps the next great step forward in the evolution of destroyers, and enormous amount of credit is due to the Admiralty Experimental Station at Portsmouth which brought oil-fuel burning apparatus to the perfection which is now known. One cannot help feeling that there must be some engineer officers whose names ought to be made public so that due honour might be paid them for their work in connection with one of the greatest improvements for war vessels, especially as it placed this country far ahead of the rest of the world for many years.

In 1910 the Admiralty, at Admiral Jellicoe's initiative, gave Messrs. Yarrow almost a free hand to do the best they could with a certain sum of money. The result was an outstanding design from which the "Firedrake," "Lurcher," and "Oak" were built. Their dimensions were 255 feet long by 25 feet 7 inches beam, and each was fitted with Parson's impulse reaction turbines and three oil-burning Yarrow boilers. One of these vessels on the official trial of eight hours duration obtained a speed of 35·354 knots.

The next important advance was in the direction of superheating. It had been long known that superheating offered great advantages both as regards economy and reliability, but in spite of many attempts it was not looked upon with great confidence for marine purposes. It was, however, so attractive that a special marine superheater was designed and fitted on one side of the Yarrow boiler, Fig. 1, by which arrangement

the superheater is placed under control, and that without seriously interfering with the total output of the boiler. If too much superheat is being obtained it is possible to send a larger proportion of the gases up the side of the boiler where there is no superheater, and although there might be a trifling loss in efficiency, yet the total output of the boiler is not substantially reduced. If the superheat is not sufficient, then more of the furnace gases can be sent up the side of the boiler on which the superheater is placed. This control of the amount of superheat was found very valuable, especially in the experimental stage.

It may here be mentioned that with a properly designed Yarrow boiler having the superheater on one side that higher efficiencies of the boiler plant have been obtained than with a boiler without a superheater, that is to say, more heat units have been transferred from the oil fuel to the steam produced. This result is rather remarkable, and points to the high efficiency of heat transference in a well-designed superheater.

Owing to the adoption of superheating, in 1913 and 1914 we were again able to produce a destroyer which had a very high overall efficiency. Although superheating had been tried in previous vessels yet the most successful results were obtained in vessels of the "Miranda" class in 1913 and in 1914, and it was on this type which Messrs. Yarrow concentrated during the war period.

These vessels showed plainly the advantage of superheating for war vessels apart from efficiency, namely, the ability to rapidly increase speed. It is necessary to exercise great care when increasing speed rapidly on account of the water which flows with the steam, and on account of the condensation which takes place in the engines and turbines while they are being heated up to the full-speed temperature. This presence of water is completely avoided if the steam is superheated, because the superheater itself is a large reservoir of heat, so that although the rate of evaporation in the boilers is very rapidly

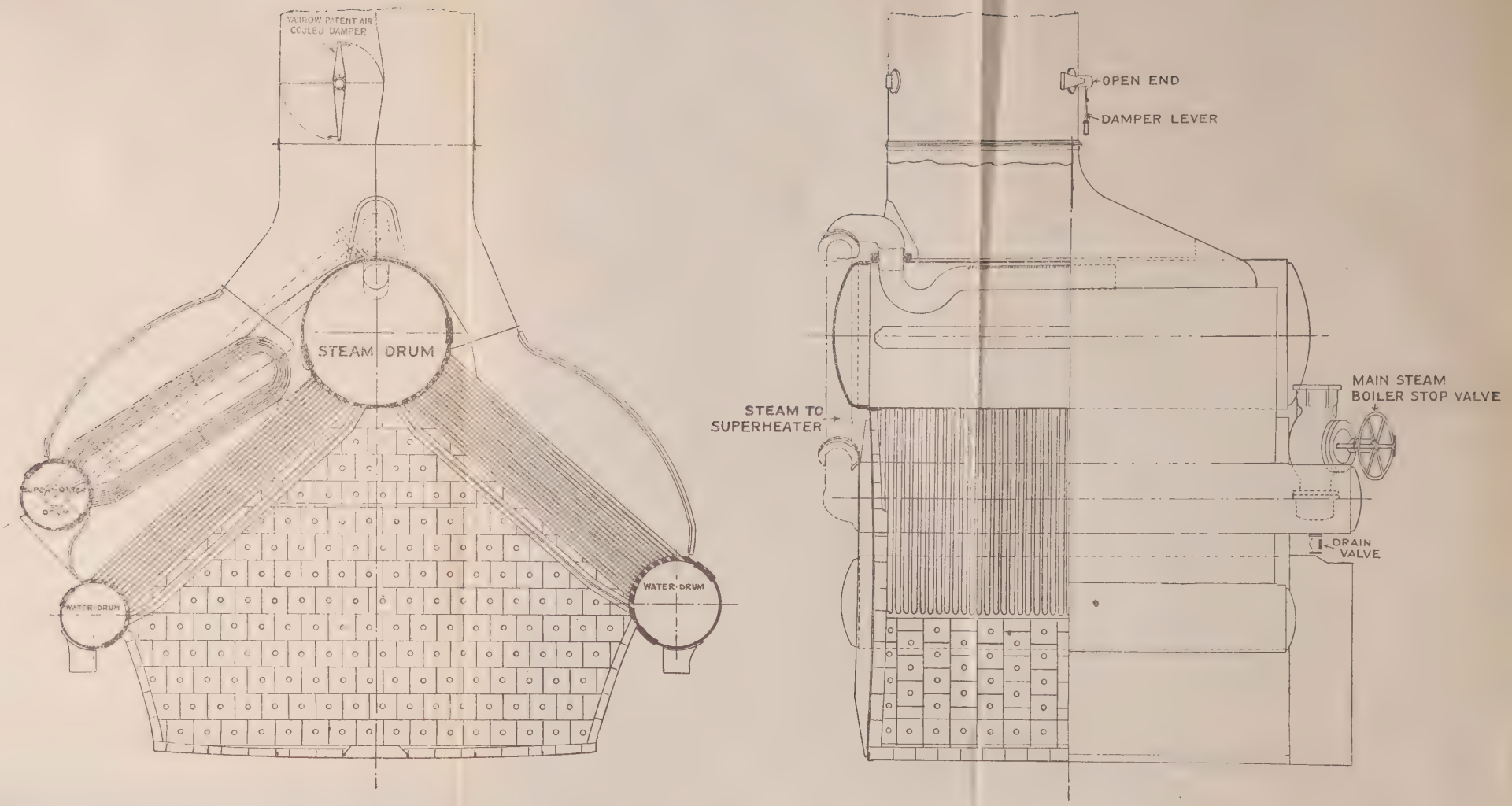

YARROW PATENT AIR COOLED DAMPER
STEAM DRUM
WATER DRUM
WATER DRUM
OPEN END
DAMPER LEVER
STEAM TO SUPERHEATER
MAIN STEAM BOILER STOP VALVE
DRAIN VALVE

Fig. 1.

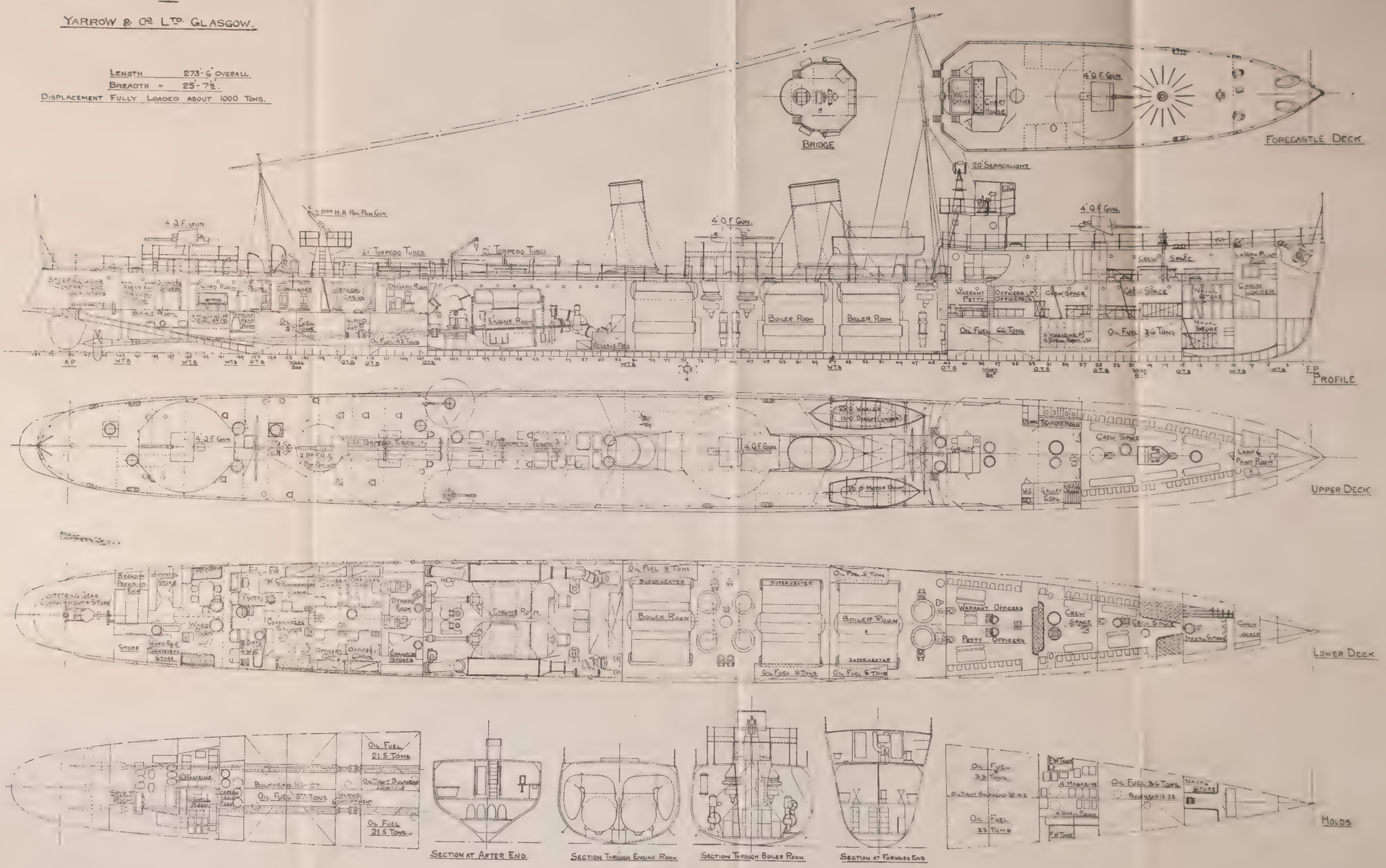

OCEAN GOING TORPEDO BOAT DESTROYER
BY
YARROW & Co LTD GLASGOW.
LENGTH 273'-6" OVERALL
BREADTH = 25'-7½"
DISPLACEMENT FULLY LOADED ABOUT 1000 TONS.
BRIDGE
FORECASTLE DECK
PROFILE
UPPER DECK
LOWER DECK
HOLDS
SECTION AT AFTER END
SECTION THROUGH ENGINE ROOM
SECTION THROUGH BOILER ROOM
SECTION AT FORWARD END

Fig. 2.

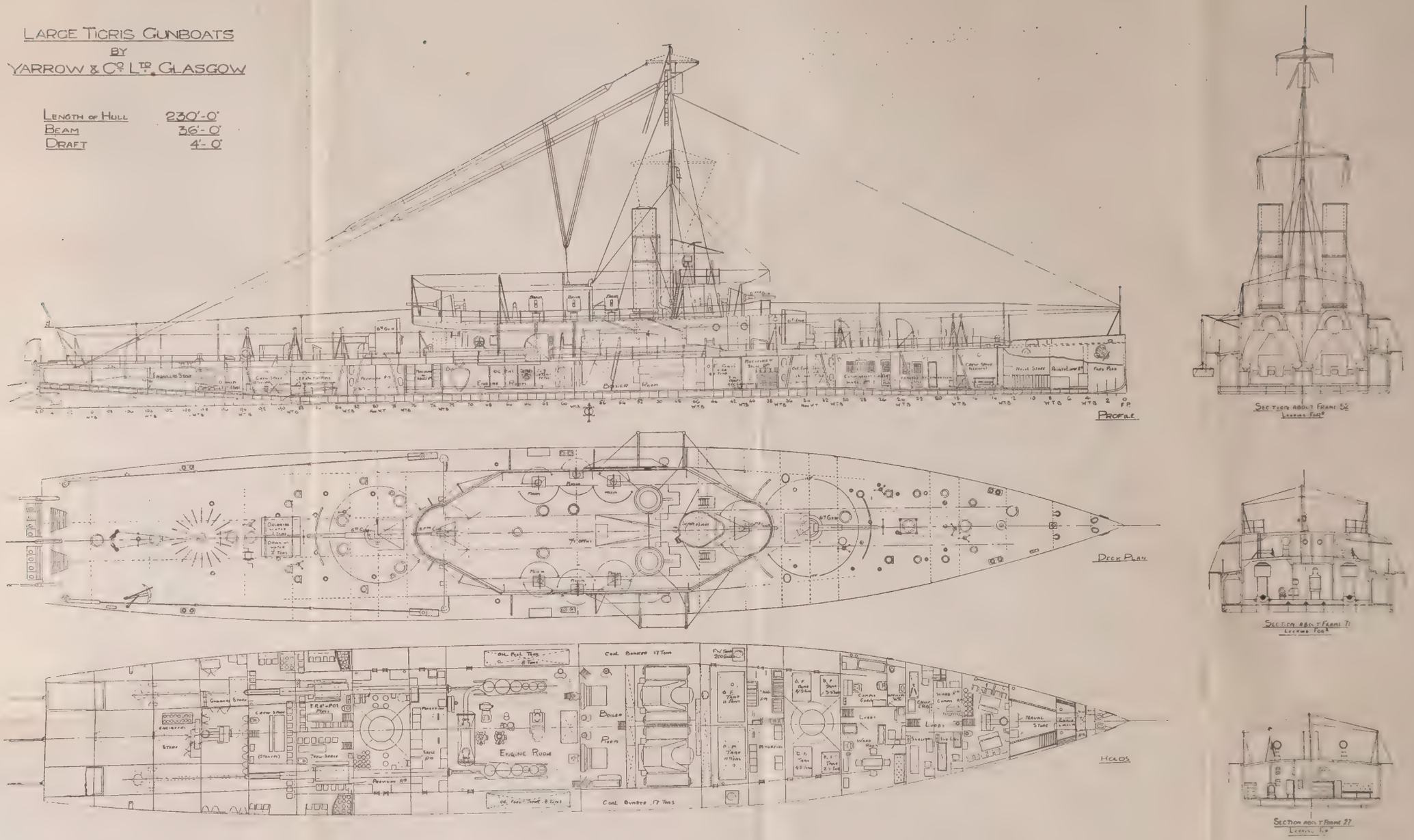

LARGE TIGRIS GUNBOATS
BY
YARROW & Co. Ltd. GLASGOW
LENGTH OF HULL 230'-0"
BEAM 36'-0"
DRAFT 4'-0"
PROFILE
DECK PLAN
HOLDS
ENGINE ROOM
BOILER ROOM
COAL BUNKER 17 TONS
SECTION ABOUT FRAME 56
SECTION ABOUT FRAME 71
SECTION ABOUT FRAME 27

Fig. 3.

YARROW & Co. LTD. GLASGOW

BEAM SCALE

increased, yet the steam arrives at the engines perfectly dry, and in most cases superheated, thus having some surplus heat available in order to raise the temperature of the turbine itself. A further advantage of superheating is that the engine-room is much cooler and consequently more comfortable. It is always noticed during a race in which destroyers take part that those fitted with superheaters get away much quicker than those using saturated steam, and a start of a mile or two is a very valuable asset in a fight.

Vessels of the "Miranda" type are about 270 feet overall, with a beam of 25 feet 7 inches, and a depth amidships of 16 feet 3 inches, Fig. 2. They have three Yarrow superheating-boilers, and are fitted with two turbines of the Brown-Curtis type driving directly the propeller shafts without the intervention of gearing. Brown-Curtis turbines were applied to these vessels on account of the large clearances in this type of turbine which made the use of superheated steam quite safe. Sir Thomas Bell, Engineer-Commander Wood, and Mr. Pigott deserve great credit for the investigations they carried out at Clydebank to make these Brown-Curtis turbines a success not only on destroyers but also on much larger vessels.

In the first vessels of this class a speed of 35 knots and a radius of action of 2,500 knots at 15 knots was guaranteed. In the last vessel of the class, the "Tyrian," a speed of 39·7 knots and a radius of action of 3,267 knots at 15 knots was achieved. This speed was obtained on the Skelmorlie measured mile in deep water, which is recognised as being the standard mile for high-speed vessels, it being well known that in water of a less depth the hull resistance is reduced at high speed and fictitious results may be obtained.

When speaking of the measured mile it may not be out of place to propose that a new deep water measured mile be set up off the north end of Arran, close to the Cock of Arran, and running approximately north-east and south-west. On this course there is plenty of room at the end for the largest

vessel to turn round safely and to attain the full speed before entering on the measured distance, while the depth of the water is not less than 40 fathoms.

It is sometimes overlooked how much power is absorbed in accelerating a vessel after the speed has been reduced by a turn at the end of the measured mile.

From careful surveys that have been made off the Cock of Arran, it may be possible to obtain a base two sea miles long, which would lead to more accurate results at high speeds. The measured distance would be in a sheltered position, clear of the traffic, and it would have the great advantage of the course being parallel to the shore. Anyone who has run high-speed vessels will know the difficulty which the pilot has in quickly getting his bearings, for when travelling at forty knots there is not much spare time to get the correct direction after the turn at the end of the mile, and the direction of the line of the shore is a better guide than swinging compasses. The only reason for proposing a new mile is because the large vessels and high speeds of to-day make it undesirable to run so near the growing excursion traffic and so close to the foreshore of a residential neighbourhood.

One of the most satisfactory features of war experience is that vessels of the "Miranda" class suffered little or no damage due to sea conditions. They proved quite strong enough for the various kinds of work that they were called upon to perform, sometimes under the most trying circumstances.

The "Mounsey," under command of Lieut. Craven, was the means of saving 696 people from H.M.S. "Otranto." The sea was very rough at the time, and the "Mounsey" could not lie alongside the "Otranto." She had to steam slowly past while the crew of the latter jumped to her deck, which manœuvre she repeated several times. The bumping to which the destroyer was exposed during this operation can be easily imagined, but the structure was uninjured.

Another case of interest as showing the strength of these

vessels was when the "Musketeer" went to rescue the crew of the "King Edward." The "King Edward" had overhanging sponsons, and while taking the crew off in a heavy sea, the destroyer got underneath the sponsons which were descending at every roll of the ship on the deck of the destroyer and severely punishing her. Incidentally it may be mentioned that there were some high-explosive shells in the ready racks on the deck of the destroyer which caused the captain a good deal of anxiety each time the sponson struck the deck, but fortunately none of them went off. In this case several plates were actually torn away, but the main structure was uninjured, and she was quickly repaired and again ready for active service.

It is not generally realised how severe are the tests to which high-speed vessels are subjected by the gun armament. When one considers the recoil of a 4·7-inch gun on such a light structure, or the recoil of a 4-inch gun repeated 20 times a minute, it is remarkable that no ill effects are experienced. One of the tests on a gun trial is that a man should be able to keep his eye on the sighting telescope while the gun is being fired. If there is the slightest yield in the mounting, apart from the recoil chamber, it will be seen that the telescope is likely to strike the man a nasty blow. The structures are so designed that the gun-layer has no difficulty in keeping his eye fixed on the target even while the gun is being fired.

The success of these light structures is in a measure due to the uniformity of elasticity longitudinally, which is a great source of safety. Some vessels have no doubt come to grief through sudden changes in strength, and it appears that uniformity of elasticity is one of the most important points in this class of light construction.

I think you will agree with me that special credit is due to the designing staff both of ship and engine departments, which can successfully produce a high-speed destroyer, and any firm who have constructed these vessels will know the accurate

workmanship which is required and obtained by special overseers appointed by the Admiralty for this type of vessel.

The direction in which further advances in speed may be looked for are as follows.—

a. Improvements in the shape of the hull, so as to reduce the hull resistance.
b. Improvements in the shape of the hull in wake of the propeller, so as to increase the propeller efficiency.
c. Perfect balancing of the propeller, and the removal of the propeller as far as possible from any disturbance which may be caused by the propeller brackets.
d. Reduction in the weight of machinery by the adoption of high-speed turbines.
e. Reduction in the weight of machinery by increasing the output of steam from the boilers.
f. By the careful elimination of any items which are not necessary for the ordinary upkeep of the ship. To provide for extraordinary occurrences is handicapping the ship by carrying weight which will probably never be used.
g. Reduction of the skin friction by eliminating all outside transverse laps, especially at the forward end of the vessel, as first pointed out by Mr. Baker.

During the war Messrs. Yarrow were also called upon to design and construct some high-speed gunboats for river purposes, known originally as the China gunboats. In such vessels the problem of speed is entirely different from that of a destroyer.

It is well known that they were ordered by Lord Fisher for use in Mesopotamia, and he gave Messrs. Yarrow an entirely free hand with respect to their design; the only stipulation being that they were to be ready for service in the shortest possible time, and that they were to be a success. Sixteen small vessels were designed and built at Scotstoun, and 12

larger vessels were designed at Scotstoun and built by well-known firms, Messrs. The Ailsa Shipbuilding Co., Messrs. Barclay, Curle & Co., Messrs. Lobnitz & Co., Messrs. The Sunderland Shipbuilding Co., and Messrs. Wood, Skinner & Co. The problem was to carry a certain armament at the highest possible speed on a shallow draught, and at the same time to provide good accommodation for the crew. In the case of the smaller vessels the draught was not to exceed 2 feet 6 inches, and in the case of the larger vessels the draught was not to exceed 4 feet 6 inches. To achieve this result the vessels had to be constructed with a flat bottom, and in order to provide for propellers large enough to utilise sufficiently the power required for the speed, the vessels were fitted with tunnels, so that when at rest the propeller was only half immersed, and when running the tunnel filled itself automatically, the propeller then working totally immersed. The after end of the tunnel when starting has necessarily to be below the surface of the water to allow for the expulsion of air and to provide an air lock, but when the tunnel is full and the water is flowing through it at a high velocity, the resistance of the vessel can be greatly reduced if the after end of the tunnel be raised up so as to be almost horizontal. This is accomplished by means of the Yarrow hinged flap. The efficiency of this flap can be best expressed by stating that for the same power 10 per cent. more speed can be obtained.

The particulars of these vessels are as follow:—

	Small.	Large.
Length - - -	120 feet.	230 feet.
Beam - - -	20 feet.	36 feet.
Speed - - -	10 miles.	18 miles.

The larger class is illustrated in Fig. 3.

It is submitted that, to obtain 18 miles per hour on a draught of 4 feet 6 inches when carrying two 6-inch guns is as good a performance as 39·7 knots in a destroyer.

When mentioning high-speed vessels there ought to be included such outstanding examples of naval architecture as the "Repulse" and "Hood," built by Messrs. John Brown & Co., and the "Renown," built by The Fairfield Shipbuilding and Engineering Co., which have obtained speeds never thought practicable with such gigantic ships.

One cannot help feeling proud of the part which the Clyde has played in obtaining these various record results, and as long as there is the same cordial co-operation between employers, the scientific designing staff, and the workmen, there need be no anxiety about records in the future.

Discussion.

Mr. Harold E. Yarrow, C.B.E. (Member of Council): I should like to emphasise what Mr. Marriner said in regard to the assistance rendered, and the work accomplished by the technical authorities of the Admiralty in the attainment of the high efficiency of the British Navy. Referring to the important question of research work, the suggestions which Mr. Marriner makes for future investigations impress one with the desirability of spending money in carrying out experiments and taking part in research. I think this Institution should do all in its power, by means of propaganda and in other ways, to urge upon politicians the necessity of liberally supporting and encouraging scientific investigations if this country is to maintain its position and compete successfully with other countries. Before the war the amount spent by the American Government and the German Government on research work, compared with the insignificant amount spent by the British Government, was astonishing. Although it is true that this country must harbour its resources in every possible way, it is false economy to limit expenditure on research.

Mr. Norman M. Hunter (Member): Mr. Marriner's paper, although very interesting, does not give very much room for

discussion, because it is more or less a description of special craft built by Messrs. Yarrow & Co. But to the builder of the ordinary merchant vessel it is very surprising that such light craft, or craft of such light scantlings, carry the very great weights and stand the terrific shocks they do from sea and gunfire without any damage. One is inclined to ask—Are we not still hankering after rather much weight in the construction of our ships? Mr. Marriner has told us that the success of these light craft was greatly helped by the introduction of high-tensile steel, which saved 12 per cent. in thickness. Perhaps Mr. Marriner would tell us what percentage of hull weight that saved. Is it possible that in building merchant ships better use can be made of high-tensile steel, and so produce a hull of less weight to carry more cargo. I think it speaks volumes for the technical skill and ability of Messrs. Yarrow and kindred firms that they were able to produce ships of such light construction to successfully stand up to the severe service they came through. I heartily endorse all the remarks made by Mr. Marriner with regard to the advantages of our experimental tank, and it is rather sad to think that British shipbuilders should in the past have had to go outside of their own country, particularly to Germany, to have experiments carried out. Builders of ordinary merchant vessels have not hitherto paid sufficient attention to this particular branch of research; they have been inclined to proceed too much by rule of thumb. If British shipbuilders intend to hold their own in these days of keen competition, it is necessary that every possible advantage should be taken of existing resources of acquiring such valuable information. Very great efforts are being made by builders of these special vessels to save weight; but Mr. Marriner made no remark concerning electric welding. There is a great future before it, and doing away with all overlaps in the plating by its means Mr. Marriner could still save weight, and probably put more inches on to the length-per-hour speed he mentioned.

Mr. Edward H. Parker.

Edward H. Parker (Secretary): Mr. Marriner refers to the feats accomplished by coastal motor-boats during the war. They were called upon to discharge duties of the most arduous nature, under the most trying weather conditions, at rates of speed which were certainly remarkable. The first coastal motor-boats built by Messrs. Thornycroft & Co. were 40-footers, each with a 250 horse-power engine of 12 cylinders, and on trial with complement and equipment complete their average speed was 34 knots. Succeeding boats were 55 feet in length with two sets of engines, each of 375 horse-power, and they were credited with speeds of 40 knots on trial when loaded. Such praiseworthy performances, however, are entirely eclipsed by recent hydroplanes, for some of which speeds of 90 miles per hour have been claimed. I am pleased that Mr. Marriner draws attention to the matter, and gives reasons why German destroyers frequently outdistanced British destroyers during hostilities, because occasionally the press adversely criticised the efficiency of some of the latter and wondered why they were outpaced by their rivals.

Alluding to the advantages accruing from tank experiments, especially when applied to high-speed vessels, Mr. Marriner says that 20 years ago it was necessary to go to Germany in order to have such experiments carried out. Probably Mr. Marriner is unaware that 20 years before that Mr. (now Sir Alfred) Yarrow realised the importance of tank trials, and that a series of experiments upon torpedo-boat models made from one of his typical designs were carried out at the original tank in Torquay to determine the relative effect of beam and draught on resistance. Sir Alfred Yarrow could write a most fascinating book on the researches he has made upon the resistance of hulls and the efficiency of screw propellers, and it is really a pity that he has not done so.

With reference to the saving of weight in the hull of the "Sokol," by substituting aluminium for the cabin fittings, many years before she was built Sir Alfred Yarrow constructed

a torpedo boat the hull of which was entirely of aluminium, and no doubt from that vessel information was obtained which enabled Messrs. Yarrow & Co. in later years to build these light structures so successfully.

Mr. William S. Watson (Member): I am quite sure that many present, like myself, when they saw the photographs of Messrs. Yarrow's ships thrown on the screen, must have renewed their youth. I remember some of these photographs appearing in the first special marine number of Cassier's Magazine many years ago. The subject then dealt with was the balancing of reciprocating marine engines. I recollect the stern view and the bow view of a destroyer, with her propellers stationary, showing the ripples issuing from her ends as the reciprocating engines, balanced and unbalanced, were running on board the vessel. I always felt in that connection, if people had thought, they would have seen that it was feasible to run an engine in a shop with a belt, to find out whether it would sit on its seat or not, as it was unnecessary to have the engine fully loaded to let the reciprocating weights set up the tilting action that gave so much trouble in the unbalanced engines of early days. Mr. Marriner spoke of the desirability of having a new measured mile, and named a course running south-west and north-east off the Cock of Arran. There is a measured mile at the north-east corner of Arran, laid out by the Admiralty during the war, because of the congestion on the Skelmorlie mile. My firm welcomed that mile very much, as it was a great deal nearer to our yard at Troon, and kept us free, when trying moderate-speed vessels, from the dangers and troubles that accrued to such vessels on the mile at Skelmorlie, when in competition with 40-knot destroyers steaming past them. The mile was so congested in those days that it was hardly safe for 17-knot vessels to use it. No doubt Mr. Marriner will agree with me that a good measured mile properly used is a means of research, because, if you have not a reliable mile by which to gauge your speed, you cannot be sure that you have reached 39·7 knots.

Mr. William S. Watson.

In connection with the reduction in weight of hulls, which Mr. Marriner says is a desirable thing to achieve, and the reduction in weight of machinery, I should like to ask him if he learned very much from the Report of the Admiralty Committee on the Strength of Destroyers, which was set up many years ago, and which investigated this work in a most heroic way, going the length of breaking a destroyer by supporting her at the two ends and leaving her unsupported in the centre? No one, of course, but a Government could experiment on that scale. It would be interesting to know if Mr. Marriner found he had to change his practice much after the conclusion of these experiments. The experiments followed upon the disastrous loss of the "Cobra," in the North Sea, when going from the Tyne to the South with a new turbine outfit.

It has been my fortune to be called upon to repair destroyers, submarines, cruisers, and all kinds of craft during the war, vessels I only knew of by name, or heard of through the technical press. Frequently destroyers had to be overhauled and sent back to Admiral Jellicoe in ten days; often it was not an easy task to complete the necessary work in the time stated. Under certain circumstances this could not have been achieved at all had it not been for the sterling whole-hearted assistance given by the ship's company to the contractor, and in that connection one very interesting case came before my notice. The "Attack" was in our No. 2 dock, with both propellers damaged, and the stern bushes very badly worn, because one propeller had a large piece removed from it, and the absence of balance therein had caused the propeller to work the shaft round in such a way that it ground out the after bush far more than the Admiralty permitted. The correct mixture of white metal for the after bushes was obtained from Messrs. Yarrow and new propellers from one of the dockyards in the South, and the repairs were carried out in the time given. Although very busy, we still had time to make friends of the commanding officer, Lieut. Callaghan, and the chief engineer,

Eng.-Lieut. Colquhoun. Imagine our pleasure not long afterwards to see in a report from, I think, Admiral Beatty to the Admiralty in connection with the fight at Heligoland Bight, that twice during the course of the action the admiral-in-chief was enabled to transfer his flag from a damaged ship to a new one through the exceptionally able seamanship of the commanding officer and crew of the "Attack." To return to the question of balancing, which must have had a very good effect on the reduction in hull weights, it will be within the knowledge of many that Sir Alfred, then Mr. Yarrow, had at one time a very fine three-crank model upon which he could place balance weights. This model was hung on springs, and turned by a small electric motor. Without balance weights the model jumped about in a rather strange manner; but with balance weights added the model would stand steadily on the springs, while the electric motor revolved the shaft. That was a good way of showing to a public, then untrained in these matters, how serious the stresses set up in a ship could be through having an unbalanced engine on board. Many twin-screw mine-sweepers and single-screw sloops built for the Government during the war were fitted with unbalanced three-crank engines, and in some mine-sweepers, when the engines were running at 270 revolutions per minute, the eduction pipes broke, and the engines had to be lifted out, balanced, and replaced. It is rather remarkable that such a thing should occur in the twentieth century, with all the information available in this country regarding three-crank engines.

Mr. Marriner referred to the China gunboats, to their 18 knots speed, to their draught of 4 feet 3 inches or 4 feet 6 inches, and to the fact that the draught was much less than the diameter of the propeller. My firm were entrusted with the building of two of these boats, and their construction was one of my happiest experiences. I never thought that one could carry out the kind of work that Messrs. Yarrow were in the habit of doing; but I soon found that Messrs. Yarrow's officials

Mr. William S. Watson.
were more than willing to help their less experienced contemporaries, and that with a very plentiful supply of drawings, etc., it was possible to build these vessels so that they would realise the speed Mr. Marriner referred to with 4 feet 3 inches draught, vessels with exceedingly light scantlings, yet able to stand the shock of 6-inch guns fired from their decks. The whole paper does not lend itself to much technical discussion; it is a review of very interesting developments, and to some extent it is reminiscent. If Mr. Marriner is agreeable, I should like him to give us the benefit of his experience on one other point. In connection with balancing, there are two or three schools of thought. One advocates balancing all the reciprocating weights and not the over-balanced rotating ones. Others say only balance the horizontal forces and let the residue go in the vertical plane. Some put balance weights on the forward crank and the after crank only, and some again on all three. Perhaps Mr. Marriner will say which of these systems he advocates, because I know that the three-crank engines in the large China gunboats designed by his firm ran at 350 revolutions without the slightest vibration in the hull, and that his firm have delivered destroyers with engines which ran at 450 revolutions. This could not possibly have been done unless the engines were so well balanced as to keep still on their engine seats, while the men who had to fight the ship could do so on a steady platform.

Mr. James Anderson (Member): The first coastal motor-boat with which I became acquainted was fitted with twin-screw Thornycroft engines with the cylinders cast *en bloc*, the one engine being set a little ahead of the other. One had reversing gear, and the other was coupled up with a clutch. When entering harbour one engine could be stopped and the boat manœuvred by the engine with the reversing gear. Starting was effected by compressed air, and it always struck me that that was one of the weak points in these boats. Compressed air bottles were charged up at a base, and if lucky there was

Mr. James Anderson.

enough air to make six starts; if unlucky, perhaps only three; then the only way to start up again was to couple up one engine and get towed by some friendly boat at a speed of from 8 to 10 knots, which was sufficient to make the engine revolve rapidly enough to secure firing. The difficulty of making a start mattered very little in the absence of Fritz, but in his presence it was awkward. These motor boats, although very fast, could not carry a heavy armament. With big engines taking up nearly all the space below, there was very little accommodation. The complement usually consisted of two deck officers, two engineers, and one wireless operator. As the boats were uncomfortable at sea, the engineers in particular had a very unpleasant time. They could not stand up, and practically had to lie down alongside their engines. In nine cases out of ten they were originally chauffeurs who had never seen the sea before, and what they had to suffer lying on the engine-room floor plates amidst vapour from fuel and lubricating oil can better be imagined than described, yet they stuck to their work splendidly. If the Admiralty really knew the hardships that these mechanics suffered they would have instituted a special medal for them, as well as for the wireless operators. The latter were located in a little box, just large enough for them to sit huddled up with their listeners on and to work their instruments. The commanding officers were nearly all R.N.R. lieutenants, while the junior officer was in most cases a R.N.V.R. officer with engineering experience, so that he could lend a hand in the engine room if required. The work accomplished by these boats, taking everything into consideration, was, I think, marvellous. The way they were handled by their respective commanders was a treat to witness, and they performed the most daring exploits in attacking all classes of enemy vessels. Submarines, destroyers, and, I believe, even cruisers, suffered from them. They went into Ostend, I think, before the great raid and blew up one of the dock gates, consequently the Germans

Mr. James Anderson.

could not get their submarines out for quite a long time afterwards. As previously stated, the Thornycroft engines were all made with cylinders *en bloc*, 12 in most cases. Later engines supplied by the Green and Sunbeam Companies, and I believe also by Thornycroft, had all independently cast cylinders.

One hull I saw was more or less elliptical in section, built on the double diagonal principle, the planking starting on one bow and finishing on the opposite quarter; each strake from port to starboard was one complete plank running underneath the body. The framing, keelson, and stringers were made of wooden lattice-girder work, as was also, practically speaking, the engine seat. The framing was on the girder principle. Boats of this type were petrol driven, but reliable information regarding their speed was very difficult to ascertain, for most captains rather exaggerated the merits of their respective vessels. The first coastal motor-boats, however, were comparatively short, and had a good turn of speed, but were not so fast as succeeding types, which were of greater length and improved form.

Regarding the American M.L.'s or motor launches, the average engineer learned a great deal, not so much from what was done in the matter of their construction as from what was left undone. The hull was built with a very heavy keel, light framing, and comparatively heavy planking that acted as an envelope to keep out the water. The stem was an exceedingly weak structure, and if it struck anything it became detached, and had to be replaced by a new one. These boats, of course, were all built on mass production lines. A large number of separate parts were cut out and prepared, and when boats were required the several parts were taken from store and assembled much on the line of the Ford motor car. The timber, according to the Americans, was specially selected, but if what I saw was their specially selected timber, then I do not wish to see their ordinary timber. A surprising thing in

Mr. James Anderson.

these 80-feet motor launches was that there were only two knees, and these were not grown knees. The stem was fastened to the keel with one or two nails, and practically the same method of fastening applied to the stern post. The timbers, which had been bent round moulds, were nailed to the keel, and on top of them ran a keelson. The decks were the weirdest imaginable, and reminded one of a packing case cover. In places little iron brackets were used as a fastening between the deck beams and frames. The brackets were about $\frac{1}{8}$ inch thick by 1 inch wide, and each arm of the bracket about 2 inches long, and these were held up by two screw nails of about $\frac{3}{16}$ inch diameter and 1 inch long—that was really all that held the boat together. The twin-screw engines were petrol driven, each of 220 horse-power. The normal petrol supply was 2,000 gallons, over 500 gallons of which the officers slept; care, therefore, had to be exercised in preventing leakage. The engines were interesting in many ways, and quite different from ordinary engineering practice in this country. Here internal-combustion engines are usually cased in, but these standard engines were open-fronted. The cylinders—six in number— were supported on wrought iron columns. The lubrication of the bottom ends was accomplished by a banjo frame on the cranks, the bearings being oiled by centrifugal force. Starting was effected by compressed air, and the reversing by moving the cam shaft fore and aft, and bringing the astern cams underneath the exhaust valves. The inlet valves were automatic, while the exhaust valves were mechanically controlled and water-cooled. Low-tension ignition was applied, as American engineers think it more reliable for slow running, and because of the trouble of reversing the magneto. The magneto had to reverse, and with a high-tension magneto a clutch was required to throw the driving gear out of action. An auxiliary engine of 12 horse-power was fitted for the twofold purpose of lighting the ship and starting the main engine. To this engine was attached a dynamo which could be run as a motor in starting the engine.

Mr. James Anderson.

The lighting system of the boat was quite efficient in a way, but very crude. The wiring was carried in pipes which could not be drained, and when water found its way into them all sorts of troubles were experienced. The principal source of leakage was through the deck fittings, which were of the cheapest variety I ever saw on board a boat. At about three-fourths speed with the engines running at 350 revolutions per minute, from 11 to 12 knots were realised, but the Americans claimed 18 knots at full speed.

Mr. T. A. Hayward (Member): Had the coastal boats any sheathing?

Mr. Anderson: There were only two thicknesses of planking, each about $\frac{1}{4}$ or $\frac{3}{8}$ inch.

Mr. James Richardson, B.Sc. (Member): How did the automatic inlet valves perform?

Mr. Anderson: Quite satisfactorily. There was some noise at full speed, but in ordinary work they gave no trouble. The greatest petty trouble occurred with the low-tension ignition gear. There was a tripper held up by a spring of American make. When that spring was worn out substitutes could not be purchased in this country, and new springs were made from old saw blades. The igniter points were fitted with a round piece of ordinary steel with a little tip of nickel steel shrunk on. Sometimes these tips burnt rapidly away after being a comparatively short period in use. Subsequently it was found that the best replacing material was an ordinary French nail. I understand that before the war French nails contained a percentage of nickel, which apparently just suited this particular job, for tips made from this material would sometimes last for months.

Dr. T. Blackwood Murray (President): Was a reversing switch fitted to prevent the pitting of the one hole of the igniter? That helps matters considerably.

Mr. Anderson: No; it only ran one way. The Admiralty issued orders that under no consideration were any alterations to be made, either permanent or temporary, in the engines or fittings.

Mr. RICHARDSON: What was the material of which the inlet valves were made?

Mr. ANDERSON: They were of the ordinary mushroom kind, and the exhaust valve was a conical valve.

Mr. Anderson then gave a most interesting account of his experience during the Zeebrugge raid.

Mr. JAMES RICHARDSON, B.Sc. (Member): The one ship for the navy and the war was, and is still, in my opinion, the torpedo-boat destroyer. Of all the various types of craft that were in being and were evolved before the war, the one which gained steadily in popularity, and fulfilled an ever-increasing range of duties, was the destroyer, and the Admiralty requirements in connection with the design and the building of these craft precluded our using in this country similar methods to those described by Mr. Anderson in connection with the American motor boats. With destroyers there is no doubt that improvement can still be effected. Messrs. Yarrow were in the fortunate position, and rightly so, of having a more free hand than other people, because of their very great previous experience, and they evolved a type of their own which I understand holds the record for performances, and it is that type that is referred to by Mr. Marriner in his paper.

In connection with the running of many trials of torpedo-boat destroyers on the Clyde, the one thing that always struck me most forcibly, and the one part of the whole equipment that stands out most prominently to my mind, is the Yarrow water-tube boiler. When it is considered that there are three very small boilers on board—one boiler can be quite comfortably accommodated in a space of 20 feet wide by 16 feet long by 15 feet high without firing space—and that out of that boiler 10,000 horse-power is obtained, it can only be described as a remarkable achievement. Yet the last word has not been said in the generation of steam from oil fuel, for oil fuel is absolutely necessary for naval service and desirable with the Yarrow boiler. To the end of improving boiler performance, we must look to

Mr. James Richardson, B.Sc.

higher water and gas speeds following on the results of research. We must have higher speeds of water and gas to increase the efficiency of heat transfer. In all our trial trips—and we delivered during the war 19 destroyers—we never had the slightest trouble on trial with the Yarrow boiler. Naturally, we had our trial trip troubles; but the one place which was most comfortable, where there was the least worry and the least concern, was the boiler room. Before the automatic-feed devices and oil-fuel burners were so completely developed as they are to-day, conditions in the stokehold were the opposite of comfortable.

Turbines have reached a high stage of development, and here again I think it is possible that, by utilising high-tensile materials, still further economies can be made, and, if the space occupied and the weight required by the machinery can be cut down, still higher speeds can be achieved. It is rather an anomaly that the standard auxiliaries for a turbine-driven destroyer are still generally of the reciprocating type. In Mr. Marriner's destroyer you will notice from the illustrations that turbines are used for driving the forced-draught fans; but the air, feed, and circulating pumps and electric light engines are of the reciprocating type. In time, when further experience has been gained, I think we shall have for the air pumps and the circulators rotary motion, and thereby economies of space and weight will be effected. I have often considered whether for this type of vessel electric driving of the auxiliaries could not be carried out to advantage; but until such time as we can get a light oil-fuel burning internal-combustion generating engine, it is probable that turbine or reciprocating steam auxiliaries will hold the field. The steam consumed by the large auxiliary equipment is from 8 to 12 per cent. of the total, and by fitting internal-combustion engines the fuel required by the auxiliaries could be very much reduced. Diesel generators are so uneconomical in space and weight that there is no case for fitting them at the present time.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member): The amount of water in a Yarrow boiler is, I believe, somewhere about 5 tons?

Mr. Richardson: Yes, in the earlier destroyers.

Mr. Riddlesworth: That is 15 tons in a ship. There is a tank feed containing about 20 tons on board. If one-half of this water is in circulation each particle, on a full-power trial, goes through the condensers, boilers, and turbines about from eight to ten times an hour, and it is a very curious thing to imagine a drop of water whose history contains such a cycle of changes from liquid to vapour so frequently.

Mr. W. W. Marriner: I assure you that in coming to Glasgow the welcome we received on Clydeside was one of the pleasantest experiences that anyone could possibly have had. Everyone knows Sir Alfred Yarrow's views regarding experimental research, and Mr. Watson expresses exactly what I feel, namely, that I am particularly fortunate in my connection with Messrs. Yarrow, who are always experimenting in some way or another. It is a very great privilege, and to be continually associated with new work is exceedingly interesting. Mr. Hunter asks me to state the percentage of weight saved in the hull by the use of high-tensile steel. I should not like to venture a figure at the moment. Mr. Hunter is quite correct in saying that I did not express too highly the benefits to be gained by having models tested in an experimental tank. Messrs. Yarrow have reaped an enormous advantage from the assistance of Mr. Baker at the Teddington tank. Mr. Baker has given figures showing that the average improvement resulting from experiments with a great many models was something like a 10 per cent. reduction in horse-power for the same speed, and this was due to slight modifications in the shape of the hull, which did not in any way interfere with the general usefulness of the ship. I am grateful to Mr. Parker for reminding us of the experiments which he assisted in carrying out for Mr. Yarrow at the original experi-

Mr. W. W. Marriner.

mental tank at Torquay, in very early days, to determine the relative effect of beam and draught on the resistance of torpedo boats.

I agree with Mr. Hunter that electric welding has a great future before it, but my firm have not yet felt justified in trying electric welding on a destroyer. It has rather come to the front during the last five or six years, which was war time, and they did not feel justified in trying a big experiment, but probably Mr. Hunter's remark will bear some fruit. There is no doubt that hydroplanes, to which Mr. Parker alluded, are very remarkable vessels, and it only remains for someone to construct them to withstand a reasonable amount of rough usage and rough weather; then there will be a very great development in this form of propulsion. I quite agree with Mr. Parker that if Sir Alfred Yarrow could be persuaded to write a book on his experiences in researches or experiments, it would be one of the most interesting and instructive books that could possibly be written. In the old days when locomotive boilers on torpedo boats were a source of anxiety, and when efforts were being made to obtain about three times the horse-power of an express engine with the same size of boiler, I remember that on one occasion the boiler tubes were leaking badly and the stokehold was full of steam, and Sir Alfred Yarrow was the only one who dared go down into that compartment in order to put the fire out, thereby saving the boiler and possibly the ship from total destruction. Mr. Parker said that no doubt we gained a great deal of valuable experience by the use of aluminium in the construction of a second-class torpedo boat. We certainly did, and immediately thereafter built a steel boat which was still lighter.

Mr. Watson referred to the balancing of a reciprocating engine and driving it by a belt in the shop. The expense of trying the engine in the boat itself was incurred in order to convince the public that it was the engine which caused the shaking of the vessel. It was necessary to prove that undue

vibration resulted from an unbalanced engine, and was not attributable to the propeller or eddies in the water surrounding the vessel. With regard to balancing the vertical and the horizontal component in a reciprocating engine, all I can say is that if it suits to balance the vertical, and it gives success, we naturally only balance the vertical, so with the horizontal, but if somebody wants both, then we try and please them.

The objection to the measured mile on the east side of Arran is that the course is not parallel to the shore, and it is extremely difficult to keep the correct direction in a high-speed vessel when on trial. I think one can safely add half a knot to the speed which is obtained with a battle cruiser or a destroyer when steaming on that mile owing to the certainty that some of the runs will not be at right angles to the posts. Mr. Watson desired to know if we learned anything from the report of the Admiralty Committee on the Strength of Destroyers. I cannot imagine a report on the strength of destroyers which did not contain or suggest something to help forward the knowledge of the subject. As to how much practice is changed it is very difficult to say. Such change depends on many things, and I may say—and perhaps Mr. Watson knows it from his own experience—that never are two boats built alike. An order may be received for six boats, and everybody interested says at the beginning, "Well, these six boats are going to be made alike." The first of the six starts with the turbines abaft the boilers, but before she is half finished somebody proposes something, and proposals continue to be made until the last boat of the six finishes with the boilers abaft the turbines. Everybody is trying to go one better, for no one can feel entirely satisfied with what has been done. A good result may be achieved one day, but the next day a better result must be hoped for. Concerning repair yards, I think everybody will admit that the wonderful repair work accomplished on the Clyde during the war is something to be very proud of.

THE "JAMES WATT" ANNIVERSARY DINNER.

THE "James Watt" Anniversary Dinner of the Institution, held on Friday evening, 23rd January, 1920, in the Grosvenor Restaurant, Glasgow, was attended by a large proportion of the membership of the Institution, many representatives of kindred societies in different parts of the country, and a considerable number of guests. Altogether the company numbered about 350. Dr. T. Blackwood Murray, President of the Institution, occupied the chair. The President was accompanied at the chairman's table by:—The Right Hon. The Lord Provost of Glasgow, Mr. J. W. Stewart; The Right Hon. Lord Lamington, G.C.M.G., G.C.I.E.; Mr. T. B. Morison, K.C., M.P., Solicitor General for Scotland; Sir John Ure Primrose, Bart., LL.D.; Sir Thomas Dunlop, Bart., G.B.E.; The Right Rev. W. P. Paterson, D.D., Moderator of the General Assembly; Sir William Beardmore, Bart.; Sir Thomas L. Devitt, Bart.; Vice-Admiral Sir Herbert L. Heath, K.C.B., M.V.O.; Sir Donald MacAlister, K.C.B., LL.D., M.A., D.Sc.; Lieut.-General Sir Francis J. Davies, K.C.B., K.C.M.G., K.C.V.O.; Sir Alfred Ewing, K.C.B., LL.D., D.Sc.; Eng.-Vice-Admiral Sir George Goodwin, K.C.B.; Major-General Sir Philip R. Robertson, K.C.B., C.M.G.; Sir John Lindsay, J.P., D.L.; Sir W. H. Raeburn; Sir Alexander Gracie, K.B.E., M.V.O.; Sir Archibald McInnes Shaw, C.B., D.L.; Sir James McKechnie, K.B.E.; Sir John Hunter, K.B.E., Member of Council; Dr. R. T. Moore, Past-President; Mr. E. Hall-Brown, Past-President; Sir Frederick N. Henderson, K.B.E.; Sir James Kemnal; Colonel J. M. Denny, C.B., Member of Council; Colonel J. Smith

Park, M.V.O., Member of Council; Mr. W. W. Lackie, C.B.E., Past-President; Mr. R. A. McLaren, O.B.E., Vice-President; Rev. John Smith, D.D.; Mr. J. R. Harrison; Com. Laurence MacBrayne, M.A.; Mr. Andrew Scott; Mr. William Mills; Mr. Robert Paul, J.P., Member of Council; Lieut. Thomas D. Galbraith, R.N.; Mr. N. O. Fulton; Mr. W. B. Hird, M.A., President, Scottish Local Section Institution of Electrical Engineers; Mr. H. Walker; and Mr. Thomas Miller.

The croupiers were Mr. James Brown, C.B.E.; Mr. G. A. Mitchell; Mr. R. D. Moore, B.Sc.; and Mr. Robert Robertson, B.Sc.

Apologies for absence were intimated from:—The Duke of Argyll, The Marquis of Graham, The Marquis of Linlithgow, Earl Beatty, Earl Haig, Lord Blythswood, Lord Newlands, Lord Weir of Eastwood, Sir George T. Beatson, Sir Archibald Hunter, Sir Harry McGowan, and the Lord Provost of Edinburgh.

Mr. T. B. Morison, in proposing "The Imperial Forces," said that the toast would have represented 18 months ago about 8,000,000 of the flower of the British Empire. Now the Imperial Forces were being reduced, and at the end of March they would number about 300,000 men. But they had duties in peace as well as in war, and they had to be relied on for maintaining law and order, and for preventing oppression and tyranny, from whatever quarter these were threatened. The war had increased the number of points which required garrisons, and provision had to be made for garrisoning the Colonies and other parts of the world of which Britain had charge. In considering the Imperial Forces, the future of the Territorial Forces should not be forgotten. The sacrifice, endurance, and courage of the Imperial Forces were beyond belief, and the history of their great deeds would never be told with fulness and accuracy.

Vice-Admiral Sir Herbert L. Heath, in responding on behalf

of the Navy, said he believed naval officers were supposed to make what were called "breezy" or "windy" speeches. This was not a night for that; he supposed it had got to be a "steamy" speech instead. There was no doubt the discoveries of James Watt affected the life of those whose business it was to go to sea more than anyone else. By the application of his discoveries time and space, so far as the sea was concerned, were very much mastered. The effect of that was first to create, and secondly to bind together this great Empire. The easier the communications and the greater the rapidity of communication the more sure was the Empire of being bound together. It was the honourable duty of the Royal Navy to see that those communications were never interrupted. So far as actual fighting was concerned, he did not know that steam had really made any great difference. Of course, it helped the raider, such as the "Emden," to get about all over the world, and to pop up at unexpected places. At the same time it enabled those who were in charge of the opposite side to reduce strategy generally to definite and certain lines. He only knew one case in which the discoveries of James Watt had any adverse effect on the Navy. There was a very fine frigate which had been fitted with a steam engine. The captain was a very fine sailor. He went to sea very proud of his ship and very proud of his command, and the first time he had to go into harbour he went in with all his sails set and with his engine running. He went through all the proper performance for shortening sail, but when he came to the place where it was time to let go his anchor, to his horror the cable parted and the ship went high and dry ashore. As usual on these occasions, he was tried by court martial. His defence was short and sweet: "May it please your Honourable Court, I can only say I forgot I was a steamer." As to the future of the Navy, he would not care to see it too much reduced.

Lieut.-General Sir FRANCIS J. DAVIES, who replied for the Army, drew special attention to the position of the Territorial

Forces. These Forces at present, he said, consisted almost entirely of officers, but he hoped that this state of affairs would shortly come to an end, and that it would be found possible to re-establish all the old units. He was sure that the 52nd Division would before long come to life. At present it consisted of one officer who was present at that gathering.

Lord LAMINGTON submitted the toast of "Our Commercial Interests." He said: Before he came he asked Mr. Parker how he was to propose "Commercial Interests" in these days without having any reference to politics, but he was assured there must be no politics, and that disheartened him very considerably. Into every form of life at the present time politics entered. And when they reflected upon the future, with the necessity that commerce should be on the best and and surest foundations to meet the great debt we owed—he thought some eight thousand millions—it was very obvious that in some form or other politics entered the whole subject matter of the toast. It was only the previous day he was reading some interesting passages on what should be our future policy as regarded trading with Germany. When the German mark had depreciated from twelve pence to one penny, it was asked how Germany was to pay off one thousand millions of an indemnity within twelve months unless we helped to rehabilitate her trade. That enormous sum could not be extracted unless Germany had the means to pay. He had also had letters from Germany pointing out the very pitiable condition of the great mass of the people. There was great luxury on the part of those who had money, but the position of the vast mass was pitiable. There, again, politics entered into the decision to be arrived at. Were we to do our best to put Germany in the position of being one of the great trading nations of the future, or as conquerors to hold her in extreme poverty? There was also the great international difficulties of exchange. The Americans had said that the great necessity was work, and that given work the trade of

the world would find itself controlled and guided into its proper channels. That was good advice. He was glad to think that on the Clyde the output of shipping for the past twelve months had shown what could be done, and what was being done to regain our position as being the greatest shipbuilding nation in the world. How many years it would take to get back our old position he did not know, but he believed that in this neighbourhood, to a great extent, the difficulty was being solved. It was obvious that, after coming through five years of devastation, there must be an enormous amount of leeway to make up, and if only Government control could be got rid of our commerce would swim along in one great broad current. Government Departments did not increase the volume of trade, and so did not do any actual good. It was very remarkable indeed how that small river, the Clyde, should have proved the floating foundation of the prosperity of Glasgow. Less than one hundred years ago it could be forded by a man on foot at the Broomielaw. Yet the Clyde had achieved the extraordinary result of becoming the greatest shipbuilding centre of the world. He believed that the common level-headedness of all classes of the community—he desired to see fair play—would soon again put Glasgow in that very unique position she had hitherto held. He in whose memory they were assembled that night was very typical of what could be done by the individual man. He was a man who suffered from extreme ill-health almost the whole of his life, yet he fought against it, and became the great pioneer in the steam industry of the world. He found the source of energy, and applied the energy with excellent results. He (Lord Lamington) never looked at the map of the world without being filled with wonder to see how small a part of that map was occupied by the British Islands, and to reflect on their enormous world-wide influences—influences for good, influences for the peace and prosperity of the whole world—obtained chiefly, he believed, by the industry of the individual man.

Sir WILLIAM RAEBURN, M.P., who responded, remarked that, while he esteemed it a very high honour to be asked to reply to this most important toast, he had a feeling of doubt akin to that feeling when he made his maiden speech in the House of Commons. He was rather puzzled as to why he had been asked to reply, but he thought he had got a reason from the proposer when he said that he could scarcely dissociate commercial interests from politics. He had never wanted the courage to speak his opinions on political matters as well as on commercial, and he quite agreed with the noble Lord that the two were intimately mixed up. At the same time he felt that on the present occasion he might not say what he would like to say about the Government management of commercial affairs. He noticed that one of the great lights of the Labour Party—Mr. Clynes—was saying the other day that there was no greater humbug than the sending of business men to Parliament. He asked what they went there for, and suggested that it was because it was a good club, and because the business man had aspirations towards the House of Lords. Why was it, he asked, that the Government did not make use of these business men when they got to Parliament, but immediately sent them to the House of Lords? He (Sir William) had no aspirations in that direction, but in his short experience he had heard better sense talked in the House of Lords than he had in the House of Commons. The reason why the business man did not perhaps get much scope in the House of Commons was that the very party who was making these criticisms really monopolised the time, and the back benches, occupied by people like himself, had very little chance. He was no pessimist; he was a thorough optimist at the present moment. He thought the recovery during the last twelve months had been simply marvellous, and especially during the last three months. The balance of our exports and imports looked very bad against us at one time, but had nearly been redressed, taking into account our invisible ex-

ports through interest and other things, and now we were on the upward grade. About the working men doing nothing but slacking, there was a great deal of nonsense talked. He thought they had only got to go down the Clyde and see the work going on there, and the tremendous output of shipping, and they would not think the working men of this country were not doing their duty. Trade was reviving wonderfully, and given freedom of action he had no fear whatever that the genius of the British race would succeed in peace as it had done in war. When he joined the Clyde Trust, now a good many years ago, the whole revenue was £250,000, and this year a million would be reached. He thought the Clyde was doing remarkably well at the present moment, and that the tonnage lost during the war would soon be replaced, but, speaking as a shipowner, he would be very chary in putting his money in shipping, for a slump was coming some day. Shipbuilding could not be maintained at its present rate and high freights continue also. Shipbuilders and engineers relied on the shipowners as their best friends. Time was when it was said that the shipowner always got the better of the shipbuilder, but the tables were turned to-day. There was one thing, the country could not get back to pre-war times till Government control was taken off. There was great talk at present about the nationalisation of everything. Nelson had four maxims. These were self-reliance, fearlessness of responsibility, power of initiation, and fertility in resource. He would like to ask that distinguished company if they believed any of these qualities were to be found in any Government Department.

The remaining toasts were "James Watt," which was honoured in silence, and, "Our Guests," proposed by Sir John Ure Primrose, and acknowledged by Sir John Lindsay, Town Clerk of Glasgow.

MINUTES OF PROCEEDINGS.

SIXTY-THIRD SESSION.

The First General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 18th November, 1919, at 7.30 p.m.

In the unavoidable absence of Mr. Alexander Cleghorn, the retiring President, Mr. W. W. Lackie, C.B.E., Past President, occupied the chair.

The Minutes of the Annual General Meeting, held on 29th April, 1919, having been printed in the billet calling the meeting, were held as read, and signed by the chairman.

Dr. R. T. Moore moved the adoption of the Report of the Council and Treasurer's Statement for 1918-19, and said that, on account of increased taxes and the higher costs of material and labour, there was a deficit of £361 9s. 3d. on the year's working. This sum included a subscription of £150 0s. 0d. to the funds of the Royal Technical College, donated in recognition of the privilege kindly granted by the college authorities which enabled the Institution to hold its sessional meetings in the college during the war period. He hoped that the cost of paper would shortly be reduced, and that the expense of printing the proceedings would not be so great in future. The question of finance was at present being carefully considered by the Finance Committee.

Mr. Robert Robertson, B.Sc., seconded, and the Report and Treasurer's Statement were unanimously adopted.

The Chairman said it gave him great pleasure to introduce their new President, Dr. T. Blackwood Murray. Dr. Murray was well known to engineers in Glasgow and the West of Scotland. He had brought renown to the city by his work in

connection with the motor car industry, and his ability was recognised when Edinburgh University conferred upon him the degree of Doctor of Science. He knew that Dr. Murray would maintain and uphold the best traditions of the Institution, and that under his guidance it would prosper. He had much pleasure in asking Dr. Murray to take the chair.

The President, in taking the chair, responded in suitable terms, and afterwards delivered his inaugural address.

Mr. Harold E. Yarrow, C.B.E., in proposing a vote of thanks to the President for his address, said everyone knew the important part which the motor vehicle had played during the war, and they felt justly proud in having as their President one who had taken such a prominent part in the development of this means of transport, and whose firm so largely contributed to the successful results attained in France and elsewhere with regard to the transportation of men and supplies to the armies during the war. The future of road transport had such great possibilities before it that Dr. Murray's address was particularly interesting at the present time, and as it covered the subject so very thoroughly it would form a valuable addition to the transactions of the Institution. He had great pleasure in now proposing a hearty vote of thanks to the President for his address.

The vote of thanks was carried by acclamation.

A paper entitled " Photo-elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members," by Prof. E. G. Coker, M.A., D.Sc., F.R.S., K. C. Chakko, M.Sc., and Y. Satake was read, and the discussion thereon postponed till the next meeting.

The following candidates were elected:—

As Members.

Anderson, David Martin, Engineer, 5 Queen's Terrace, Glasgow, W.

Baker, Ernest Folliott, Engineer-Commander, R.N., 8 Parkgrove Terrace, Glasgow, W.

CURROR, FINLAY MUNRO, Engineer, 21 Queen St., Waterloo, Liverpool.

DAVIDSON, ANDREW BROWN, Engineer, Ailsa, Blythswood Avenue. Renfrew.

DAW, ALEXANDER, Engineer, Bencleuch, 101 Newton Street, Greenock,

EDWARDS, HARRY RICHARDS, Engineer, c/o Messrs. Bulloch Bros. & Co. Ltd., 13 Fenchurch Avenue, London, E.C.3.

GARDNER, JOHN WILLIAMSON, Engineer, Smithfield House, Plains, by Airdrie.

HISLOP, ALEXANDER, Shipbuilder, Corra-Linn, Wedderlea Drive, Cardonald, Glasgow.

LYLE, WILLIAM, Shipbuilder, 31 Ferry Road, Renfrew.

MAAS, NORMAN NATHAN, Engineer, 18 Selborne Road, Jordanhill, Glasgow.

MURRAY, JAMES WILLIAM KELLO, Engineer, Balgonie, The Loan, Colinton, Midlothian.

MCCAW, GEORGE E., Engineer, 112 Beechwood Drive, Broomhill, Glasgow.

MACKAY, WILLIAM, Engineer, Messrs. Melville-Brodie Engineering Co., Kirkcaldy.

MACKENZIE, JOHN DONALD, Engineer, 155a St. Vincent Street, Glasgow.

MCLEAN, WILLIAM, Shipbuilder, 5 Middleton Terrace, Ibrox, Glasgow.

MACLEOD, JAMES, Engineer, 7 Ethel Terrace, Stanmore Road, Mount Florida, Glasgow.

MCNEIL, PETER BISLAND, Engineer, 9 Argyle Street, Greenock.

PATE, jun., B.Sc., GEORGE, Engineer, Carron Grange, Carron, Falkirk.

PHILBROW, WILLIAM ERNEST, Engineer, 10 Kennyhill Square, Dennistoun, Glasgow.

RIETTI, ALESSANDRO, Naval Architect, 9 Via dell'Oche, Florence.

SANDERS, GEORGE H. S., Engineer-Commander, D.S.O., R.N., H.M.S. "Colombo," c/o G.P.O., London.

SMEATON, GEORGE ARCHIBALD, Engineer, c/o Supt.-Engineer, Marine Dept., Lagos, Nigeria.

SWAN, JAMES, Shipbuilder, 19 Clifford Street, Ibrox, Glasgow.

SUTHERLAND, HUGH CAMPBELL, Engineer, 510 Springburn Road, Glasgow.

TOKUDAIJI, Baron TSUNEMARO, Naval Architect, Mitsubishi Zosen, Kaisha Ltd., Kobe Works, Kobe, Japan.

TRAQUAIR, WILLIAM GEORGE, Engineer, 217 St. Vincent Street, Glasgow.

WATT, JAMES, Engineer, 13 Thornwood Drive, Partick, Glasgow.

WILLIAMSON, JOHN, Shipbuilder, Oakbank, Cook Street, Craigton, Glasgow.

YAMAMOTO, D.Sc., NAGAKATA, Naval Architect, Manager, Mitsubishi Shipbuilding and Engineering Co. Ltd., Tokyo, Japan.

YOUNG, HENRY, Engineer, 1a Wilson Street, Hillhead, Glasgow.

YOUNG, WILFRID EDWARD, Engineer, Messrs. Yarrow & Co. Ltd., Scotstoun, Glasgow.

From Associate Members.

ANDERSON, JAMES, Engineer, Mercantile Engineers and Founders Ltd., 104 Harmony Row, Govan, Glasgow.

EDWARDS, CHARLES A., Marine Engineer, 30 Hamilton Square, Birkenhead.

HUNTLEY, JOHN H., Engineer, 20 Weirwood Park, Baillieston.

STOBIE, PETER, Engineer, 40 Derby Street, Glasgow.

WARBURG, FREDERICK NORMAN, Engineer, Alhambravej 17, Copenhagen.

From Students.

BIGGART, WILLIAM MITCHELL, Mechanical Engineer, 39 Sherbrooke Avenue, Pollokshields, Glasgow.

CHURCH, BASIL HAMPDEN, Engineer, 35 Bushmead Avenue, Bedford

CLEGHORN, jun., B.Sc., ALEXANDER, Major, Technical Dept., R.A.F., 14 Hatfield Drive, Kelvinside, Glasgow.

HALL-BROWN, O.B.E., B.Sc., ARCHIBALD, Assistant to Managing Director, Messrs. Babcock & Wilcox Ltd., Oriel House, Farringdon Street, London, E.C.4.

HUNTER, JOHN ERIC ARROL, Engineer, Braila, Bearsden.

IMRIE, DAYTON, Engineer, 58 Lauderdale Mansions, London, W.9.

MUNGALL, DAVID MYERS, Marine Engineer, 24 Millbrae Crescent, Langside, Glasgow.

MURRAY, JAMES, Engineer, Lindean, 265 Nithsdale Road, Dumbreck, Glasgow.

POOLEY, FRANCIS HENRY, Captain, Tank Corps, Dollis Hill Camp Experimental Station, Cricklewood, London, N.W.

RICHMOND, THOMAS, Engineer, 3 Rosemount Terrace, Ibrox, Glasgow.

SHAW, THOMAS E., Engineer, Menevia, Ballast Point Road, Balmain, Sydney, Australia.

WATSON, JOHN SPEIRS, Engineer, 24 Sherbrooke Avenue, Pollokshields, Glasgow.

As Associate Members.

ARMSTRONG, WILLIAM JOHNSTON, Engineer, 38 Hill Street, Garnethill, Glasgow.

CLEGHORN, WILLIAM GEORGE, Major, Shipbuilder, 14 Hatfield Drive, Kelvinside, Glasgow.

DAS, SURESH RANJAN, Electrical Engineer, 25 Kempsford Gardens, Earl's Court, London, S.W. 6.

DRYSDALE, jun., B.Sc., JOHN WHITEHEAD WILSON, Engineer, 16 Whittinghame Drive, Glasgow, W.

GRANT, ALLAN ALISTAIR, Engineer, 25 Dunolly Gardens, Ibrox, Glasgow.

HARVEY, JOHN UNDERWOOD, Engineer, 10 Newton Terrace, Sauchiehall Street, Glasgow,

JAMES, JOHN ALEXANDER, Engineer, 8 Strathearn Place, Edinburgh.

McEwan, John Noblett, Engineer, 5 George Drive, South Govan, Glasgow.

McPherson, Thomas Grant, Engineer, 142 Allison Street, Crosshill, Glasgow.

May, Norman James, Engineer, 3 Minard Avenue, Partickhill, Glasgow.

May, jun., William W., Engineer, 3 Minard Avenue, Partickhill, Glasgow.

Muirie, John, Engineer, 14 Battlefield Avenue, Langside, Glasgow.

Skelton, Godefroy, Engineer, 76 Kenmure Street, Pollokshields, Glasgow.

Smith, Thomas, Engineer, 5 Rhannan Road, Cathcart, Glasgow.

Sommerfeldt, George Hans Johan Kelland, Naval Architect, 17 Highburgh Road, Glasgow.

Stewart, Matthew Muir, Engineer, 83 Holmlea Road, Cathcart, Glasgow.

Young, John, Engineer, 106 Victoria Drive, Scotstounhill, Glasgow.

From Students.

Allan, Alexander, Engineer, 4 Haldane Villas, Scotstounhill, Glasgow.

Alexander, Thomas, Engineer, 33 Barnwell Terrace, Govan, Glasgow.

Barron, George, Engineer, 2 Hillend Gardens, Hyndland, Glasgow.

Brown, John Steven, Engineer, 56 Esplanade, Greenock.

Boyle, James Douglas, Marine Engineer, 37b Newton Street, Greenock.

Briggs, John, Engineer, Avenue Villa, Station Road, Borrowash, Nr. Derby.

Carmichael, John, Engineer, 197 West Princes Street, Glasgow.

Croll, jun., B.Sc., David, Engineer, Vredehofweg, 52, Rotterdam, Holland.

Dalglish, John, Engineer, 28 Craigpark Drive, Dennistoun, Glasgow.

Decker, Manfredo M., Naval Architect, Corso Firenze, 40, int.2, Genoa, Italy.

Dick, William, Engineer, Muirside, Braidfauld Street, Tollcross, Glasgow.

Dunn, George Arthur, Engineer, 23 Annandale Street, Glasgow, S.S.

Ferguson, James Clark, Marine Engineer, Garleffan, Kilmarnock Road, Newlands, Glasgow.

Gray, Samuel Muir, Engineer, 32 Minerva Street, Glasgow.

Hayward, Andrew Gordon, Engineer, 60 Grant Street, Glasgow, W.

Hutcheon, Donald, Engineer, Ashgrove Engineering Works, Aberdeen.

Kerr, John Bain, Engineer, 14 Woodcroft Avenue, Broomhill, Glasgow.

Kirkwood, Archibald Glen, Mechanical Engineer, 39 Garturk Street, Crosshill, Glasgow.

Loney, Charles, Engineer, 7 Leven Street, Pollokshields, Glasgow.

McIntyre, John, Mechanical Engineer, Mordun Villa, Dumbarton.

Mathewson, George Robert, Engineer, 59 Roebank street, Dennistoun, Glasgow.

Napier, Henry Andrew Muter, Shipbuilder, Milton House, Bowling.

Pollock, Colin McLean, Engineer, 11 Cumming Drive, Mount Florida, Glasgow.

Robertson, William, Marine Engineer, 5 Bute Gardens, Muirend, Glasgow.

Scott, L. H., Engineer, 33 Camphill Street, Queen's Park, Glasgow.

Semple, Peter, Engineer, 13 Howard Street, Kilmarnock.

As Students.

Benzies, Frank, Engineer, 44 Keir Street, Pollokshields, Glasgow.

Burt, David Ogilvie, Engineer, 313 Paisley Road, W., Ibrox, Glasgow.

Chalmers, Alexander, Engineer, 35 Woodend Drive, Jordanhill, Glasgow.

Clark, Martin Munro, Engineer, Pinkie Hill House, Inveresk.

Dalziel, Alexander, Engineer, c/o Porteous, 32 Scotstoun Street, Scotstoun, Glasgow.

Douglas, James, Engineer, Albert Villa, London Road, Stranraer.

Erskine, Thomas Marshall, Engineer, Brentham, 136 Terregles Avenue, Maxwell Park, Glasgow.

Fielding, William, Engineer, 2 Duncan Avenue, Scotstoun, Glasgow.

Halbert, Thomas Arthur, Engineer, 1236 Dumbarton Road, Whiteinch, Glasgow.

Harvey, Thomas, Engineer, 10 Newton Terrace, Glasgow.

Hird, Raymond Julius, Engineer, 9 Cathkin Road, Langside, Glasgow.

Jamieson, James, Engineer, 33 Smithfield Loan, Alloa.

Johnston, James A., Engineer, 3 Queen Margaret Crescent, Kelvinside, Glasgow.

Kirkwood, William P., Engineer, 2 Talbot Terrace, Scotstounhill, Glasgow.

McAllister, George, Engineer, 15 Dunearn Street, Glasgow, W.

MacGillivray, Ian S., Engineer, Dunmaglass, Bearsden.

McKerracher, Donald, Engineer, Bereholm, Lesmahagow.

Morison, Gordon S., Engineer, 150 Balshagray Avenue, Jordanhill, Glasgow.

Mowat, Daniel Gordon, Engineer, 30 Belmont Gardens, Hillhead, Glasgow.

Platt, B.Eng., Maurice, Engineer, 8 Stuart Avenue, Scotstoun, Glasgow.

Reid, W. Cecil, Engineer, Ralston, Mount Vernon, Glasgow.

Shea, James, Engineer, 36 Moray Avenue, Scotstoun, Glasgow.

Sunderland, David Maurice, Engineer, Afton Lodge, Hampden Terrace, Mount Florida, Glasgow.

TAYLOR, GEORGE ABERDEAN, Engineer, 194 Copland Road, Ibrox, Glasgow.

TULLIS, DAVID RONALD, Engineer, 10 Eglinton Drive, Kelvinside, Glasgow.

WALKER, WILLIAM PINCKNEY, Apprentice Shipbuilder, c/o St. Mary's Clergy House, 21 Burnbank Gardens, Glasgow, W.

The Second General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 25th November, 1919, at 7.30 p.m.

Dr. T. Blackwood Murray, President, occupied the chair.

The President said he was very sorry to intimate that Mr. Parker, their Secretary, had been laid aside since last Thursday, and his doctor would not allow him to attend to any business. The minutes, therefore, of last meeting would be printed in the billet calling the next meeting, and submitted for approval at that meeting. He was sure it was their desire that he should convey to Mr. Parker their best wishes for his speedy recovery.

The discussion on the paper by Prof. Coker, M.A., D.Sc., F.R.S., K. C. Chakko, M.Sc., and Y. Satake, entitled "Photo-elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members," was begun, and adjourned.

A paper entitled "The Cruiser Stern," by Mr. P. A. Hillhouse, B.Sc., was read, and the discussion thereon begun, and adjourned.

The Third General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 23rd December, 1919, at 7.30 p.m.

Dr. T. Blackwood Murray, President, occupied the chair.

The Minutes of the two previous meetings held on 18th November and 25th November, 1919, respectively, having been printed in the billet calling the meeting, were held as read and signed by the President.

The discussion on the paper by Prof. Coker, M.A., D.Sc.,

F.R.S., K. C. Chakko, M.Sc., and Y. Satake, entitled "Photo-elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members," was concluded.

On the motion of the President the authors were awarded a hearty vote of thanks for their paper.

The discussion on the paper by Mr. P. A. Hillhouse, B.Sc., entitled "The Cruiser Stern," was resumed and concluded.

On the motion of the President Mr. Hillhouse was awarded a hearty vote of thanks for his paper.

A paper entitled "Calculating Machines Early and Recent," by Dr. E. M. Horsburgh, was read.

A paper entitled "Design, Treatment, and Handling of the Snaps, etc., Used in Pneumatic Hammers," by Mr. G. Denzil Hollis, was held as read.

The following candidates were elected:—

As Members.

Beveridge, B.Sc., John Roy, Engineer, Gordon Villa, Balmoral Avenue, Belfast, Ireland.

Blyth, Robert C., Engineer, 17 Lillian Street, Toronto, Ontario, Canada.

Clark, Harold, Engineer, The Broughton Copper Co. Ltd., Hydepark Street, Anderston, Glasgow.

Crawford, B.Sc., James Buchanan, Naval Architect, Messrs. William Hamilton & Co. Ltd., Port-Glasgow.

Easthope, James, Ship and Engineer Surveyor, Lloyd's Register of Shipping, 342 Argyle Street, Glasgow.

Gillies, William M., Repairs Manager, Ayrshire Dockyard Co., Janefield, Sidney Street, Saltcoats.

Hall, John Neill, Engineer, Messrs. Laird & Son Ltd., Irvine.

Hayward, Charles Hembry, Engineer, Chanette, Centurion Drive, Mols, Hoylake, Cheshire.

Hood, James MacLay, Founder, Mount Blow, Maxwell Drive, Pollokshields, Glasgow.

Hunter, William Alfred Todd, Engineer, 8a Rumford Place, Liverpool.

Hutchison, Thomas, Engineer, Messrs. Babcock & Wilcox Ltd., Shanghai.

Laird, John, Engineer, Messrs. Laird & Son Ltd., Irvine.

Maltby, George, Engineer, Messrs. Redpath, Brown & Co. Ltd., 19 Waterloo Street, Glasgow.

McCall, David, Shipbuilder, Fernlea, Irvine.

MacKenzie, Donald, Engineer, 3 Blenheim Drive, Glasgow, W.

Robertson, John, Manager, The North-West Rivet, Bolt, and Nut Factory Ltd., Glendana, Lady Wilson Street, Airdrie.

Wallace, Duncan McNaughton, Engineer, Managing Director of J. Wallace & Sons Ltd., 34 Paton Street, Glasgow.

Wilson, Robert, Engineer, 12 Terregles Avenue, Pollokshields, Glasgow.

Wood, Robert G., Engineer, 11 Ailsa Drive, Langside, Glasgow.

From Associate Members.

Jones, Robert F., Engineer, 11 Leven Street, Pollokshields, Glasgow.

Melrose, Robert Greig, Marine Engineer, 637 Alexandra Parade, Dennistoun, Glasgow.

From Student.

Patterson, B.Sc., Robert Wilson, Mechanical and Marine Engineer, 51 Polwarth Gardens, Hyndland, Glasgow.

As Associate Members.

Dickie, B.Sc., Norman Kingsley, Civil Engineer, 142 Terregles Avenue, Pollokshields, Glasgow.

Dixon, B.Sc., A.R.T.C., Arthur, Engineer, Derwent, 30 Kelvinside Gardens, Glasgow.

Lyon, Colin Sinclair, Lieut., R.H. and R.F.A. (T.), Engineer, c/o Mrs. Sinclair, 43 Partickhill Road, Glasgow.

Mowat, Arthur F., Ship Draughtsman, 25 Iona Place, Mount Florida, Glasgow.

From Students.

McLennan, Robert George Logan, Engineer, Dorleigh, Knutsford Drive, Cliftonville, Belfast.

Thomson, David Stratton, Chief Ship Draughtsman, The Shanghai Dock and Engineering Co. Ltd., Shanghai, China.

As Associates.

Linck, George Emil, Commercial Manager, 15 Elliot Street, Hillhead, Glasgow.

Milnes, George, Journalist, 87 Union Street, Glasgow.

As Students.

Brown, William John Mackenzie, Engineer Student, 31 Dalkeith Avenue, Dumbreck, Glasgow.

Glenroy, John, Engineer, 217 Broad Street, Mile-End, Glasgow.

Greer, Arthur William Courtenay, Engineer Student, 16 Annfield Road, Partickhill, Glasgow.

Farrell, James Fraser Ewen, Mechanical Engineer, c/o Mrs. Smith, 90 Balgrayhill, Springburn, Glasgow.

The Fourth General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 20th January, 1920, at 7.30 p.m.

Dr. T. Blackwood Murray, President, occupied the chair.

The Minutes of the Third General Meeting, held on 23rd December, 1919, having been printed in the billet calling the meeting, were held as read, and signed by the President.

The discussion on the paper entitled "Design, Treatment, and Handling of the Snaps, etc., Used in Pneumatic Hammers," by Mr. G. Denzil Hollis, was begun and adjourned.

A paper entitled "The Development of Metal Construction in Aircraft," by Major John S. Nicholson, O.B.E., was read.

The following candidates were elected:—

As Members.

Borthwick, Alexander Charles, Engineer, 149 St. Vincent Street, Glasgow.

Ross, Alexander, Shipyard Manager, Messrs. Scott's Shipbuilding and Engineering Co. Ltd., Greenock.

Turner, Alexander Bertram, Engineer, 300 Langside Road, Queen's Park, Glasgow.

Wallace, Charles Vincent, Chief Draughtsman, The Mount, West Chapelton Avenue, Bearsden.

As Associate Member.

Kerr, John Dunlop, Engineer, 324 Cumbernauld Road, Glasgow.

As Students.

Biggam, John, Apprentice Engineer, Orchard Cottage, Orchard Street, Falkirk.

Wardlaw, Henry Frank, Draughtsman, 103 Dundas Street, Glasgow, S.S.

The Fifth General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 17th February, 1920, at 7.30 p.m.

Mr. R. A. McLaren, Vice-President, occupied the chair.

The Minutes of the Fourth General Meeting, held on 20th

January, 1920, having been printed in the billet calling the meeting, were held as read, and signed by the Chairman.

The Discussion on the paper entitled "Design, Treatment, and Handling of the Snaps, etc., Used in Pneumatic Hammers," by Mr. G. Denzil Hollis, was resumed and concluded.

On the motion of the Chairman, Mr. Hollis was awarded a vote of thanks for his paper.

The discussion on the paper entitled "The Development of Metal Construction in Aircraft," by Major John S. Nicholson, O.B.E., was begun and adjourned.

A paper entitled "Notes on Aircraft Production," by Prof. J. D. Cormack, C.M.G., C.B.E., was read.

A paper entitled "A New Type of Shipyard Crane," by Mr. W. Hök, was held as read.

The following candidates were elected:—

As Members.

Bewsher, Harold W., Engineer, c/o Messrs. Babcock & Wilcox Ltd. 53 Bothwell Street, Glasgow.

Brown, Robert Mackie, B.Sc., Lecturer on Engineering, Glasgow University, 65 Montgomerie Street, Glasgow, W.

Carson, John, Engineer General Manager, c/o Messrs. Harland & Wolff Ltd., Bootle, Liverpool.

Collbran, Bertram, Capt., Engineer, c/o Messrs. John G. Kincaid & Co. Ltd., Greenock.

Edgar, George Russell, B.Sc., Ship Surveyor, Lloyd's Register of Shipping, 32 Cadzow Drive, Cambuslang.

Jackson, Jun., George William, Assistant Manager, c/o Messrs. Vickers Ltd., 75 St. George's Place, Glasgow.

Macmillan, Robert Kennedy, Ship Surveyor, Lloyd's Register of Shipping, 342 Argyle Street, Glasgow.

Martin, Frank Roland, Engineer, 2 Albert Grove, Great Crosby, Lancashire.

Millar, Alexander Forsyth, Works Manager, "Gowanlea," Bo'ness Road, Grangemouth.

Millar, Charles Adamson, Ship Surveyor, Lloyd's Register of Shipping, 71 Fenchurch Street, London.

Moore, George Wilfred Gates, Engineer, 2 Hilberry Avenue, Tue Brook, Liverpool.

Niccol, James Stevenson, Consulting Engineer, 96 York Drive, Hyndland, Glasgow.

RIDDELL, WALTER, Engineer, 63 Kempock Street, Gourock.

WILLIAMS, LESLIE BERNARD, Engineer, 7 Lothian Gardens, Glasgow, W.

From Associate Members.

BORLAND, WILLIAM, 141 Stanmore Road, Mount Florida, Glasgow.

PRESTON, HECTOR INNES, 4 Millbrae Crescent, Yoker.

As Associate Members.

CRICHTON, CHARLES JOHN WOODROW, Engineer, Aon Darach, Helensburgh.

LANDER, Jun., THOMAS EATON, Engineer, Western Club, Buchanan Street, Glasgow.

MAGOWAN, WILLIAM JOHN, Engineer, 242 Nithsdale Road, Pollokshields, Glasgow.

SAMUEL, JAMES, Ship Draughtsman, 118 Eglinton Street, Glasgow.

SCOTT, ERNEST, Engineer, Invercoe, Uddingston.

From Students.

REA, PAUL, Engineer, Greenbank Place, Cathcart, Glasgow.

WALLACE, JOHN CAMERON, Heathery Knowe, Kilmacolm.

As an Associate.

LANDER, Sen., THOMAS EATON, Director, British Electric Plant Co. Ltd., Western Club, Buchanan Street, Glasgow.

As a Student.

KINGHORN, DAVID, Apprentice Engineer, 9 Kensington Gate, Glasgow, W.

An Extraordinary General Meeting was held within the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 30th March, 1920, at 7.30 p.m. Dr. T. Blackwood Murray, President, occupied the chair.

The Secretary having read the notice calling the meeting, the President briefly referred to the financial situation of the Institution, and the Council's recommendations regarding the increase of subscriptions for future sessions which had been embodied in a circular letter issued to the members. Thereafter, on the motion of the President, seconded by Mr. R. A. McLaren, O.B.E., Vice-President, the following special resolution was passed, namely:—

A. Article 46 of the Articles of Association shall be cancelled and in lieu and place thereof the following Article shall be read as Article 46:—

> Each Member shall, on election, pay an entrance fee of £1, and for the current and for each Session thereafter an Annual Subscription of £3.
>
> Each Associate Member shall, on election, pay an entrance fee of £1, and for the current Session and each of the two following Sessions an Annual Subscription of £1 10s., and thereafter an Annual Subscription of £2 5s.
>
> Each Associate shall, on election, pay an entrance fee of £1, and for the current Session and each Session thereafter an Annual Subscription of £2 5s.
>
> Each Student shall pay an Annual Subscription of 15s. but no entrance fee.
>
> In the case of Members, Associate Members, Associates, and Students elected during March and April no subscription shall be payable for the current Session.

The President then moved, and Mr. R. A. McLaren, O.B.E., Vice-President, seconded, that:—

B. Article 48 of the Articles of Association shall be cancelled and in lieu and place thereof the following Article shall be read as Article 48:—

> The liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payment, namely, in the case of a Member, by the payment of £40; and in the case of an Associate, by the payment of £30; and, in the event of such payment being made by a Member or an Associate on his admission to the Institution, the same shall be in full of entry money as well as future Annual Subscriptions.

The above special resolution was put to the meeting and passed.

The Sixth General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 30th March, 1920, at 7.45 p.m.

Dr. T. Blackwood Murray, President, occupied the chair.

The Minutes of the Fifth General Meeting, held on 17th February, 1920, having been printed in the billet calling the meeting, were held as read, and signed by the President.

Before proceeding to the business of the meeting, the President said that he had been asked by the Council to draw attention to a matter which had been under their careful consideration. Probably most of the members were aware that the Institution of Civil Engineers had recently placed before Parliament a Bill to provide for the registration of, and to regulate the qualification of, civil engineers. While he thought they were all in agreement that it was desirable to raise the status of the engineer, the Bill formed rather a dangerous document. It would put a very great deal of power into the hands of the Council of the Institution of Civil Engineers, and much depended upon the definition of the words "civil engineer." After mature consideration, the Council of this Institution felt they could not countenance the Bill. It had been considered by practically all the other engineering institutions throughout the country, and, so far as he was aware, each one came to the same conclusion—that the Bill in its present form was unsatisfactory. Consequently, he thought it might be taken that this Bill would not be proceeded with, whatever may be subsequently done. Undoubtedly, any Bill of this nature should have the sanction of all the engineering institutions in the country.

The following nominations for office-bearers were then made:—For Session 1920-21—*President*, Dr. T. Blackwood Murray. For Sessions 1920-23—*Vice-Presidents*, Mr. J. Howden Hume and Mr. Harold E. Yarrow, C.B.E. *Ordinary Members of Council*, Mr. John Dickinson; Mr. Laurence MacBrayne, M.A.; Mr. Noel E. Peck; Mr. N. O. Fulton; and Engr.-Capt. William Onyon, M.V.O.

The discussion on the paper entitled "The Development of Metal Construction in Aircraft," by Major John S. Nicholson O.B.E., was resumed and concluded.

On the motion of the President, Major Nicholson was awarded a hearty vote of thanks for his paper.

The discussion on the paper entitled "A New Type of Shipyard Crane," by Mr. W. Hök, was begun and adjourned.

A paper entitled "Experiments on Riveted Joints," by Dr. James Montgomerie, was held as read.

The following candidates were elected:—

As Members.

Aitchison, C.I.E., M.A., B.Sc., William, Colonel, Engineer, 55 West Regent Street, Glasgow.

Begg, Robert William, Engineer, Kirkwood, Coulter, Lanarkshire.

Broom, B.Sc., Alexander Morrison, Engineer, 86 Albert Road, Crosshill, Glasgow.

Brown, William, Engineer, 19 Blairhill Street, Coatbridge.

Burt, O.B.E., John Wotherspoon, Major, Engineer, Hollybank, Bothwell, Lanarkshire.

Coch, Nicolay Wilhelm, Consulting Engineer, Eysheins Gate 3, Bergen, Norway.

Holloway, Reginald, Lieut.-Col., Engineer, British Motor Buildings, New City Road, Glasgow.

Kenwright, George, Engineer, 37 Cecil Street, Hillhead, Glasgow.

Lambert, Leslie Carlton, Engineer, Hillside, Drumchapel, near, Glasgow.

Leask, Joseph, Ship Constructor, Ship Construction Branch, Navy Office, Melbourne, Australia.

Macintyre, John Duncan, Engineer, 20 Doune Terrace, Kelvinside, Glasgow.

Maclean, Magnus Norman, Engineer, 51 Kersland Terrace, Hillhead, Glasgow.

From Associate Members.

Riddlesworth, M.Sc., M.Eng., William Henry, Naval Architect, 43 Partickhill Road, Glasgow.

Williamson, John William Rea, Engineer, 16 Maxwell Avenue, Westerton, Dumbartonshire.

Woodside, Hugh Ramsay, Engineer, 65 West Regent Street, Glasgow.

As Associate Members.

Whyte, Randolph James Waddington, Engineer, Tudor House, Skelmorlie, Ayrshire.

WYLLIE, ALEXANDER TURNER, Engineer, c/o Lindsay, 219 Byres Road, Hillhead, Glasgow.

From Student.

SCOTT, GORDON HEYWOOD, Engineer, 4 Dean Road, Jordanhill, Glasgow.

As Associates.

ASHWIN, ALBERT JOHN, Shipowner, 5 Crosby Square, London, E.C.3.

CAROZZI, JOSEPH LOUIS, Editor, 91-3 Leadenhall Street, London, E.C.3.

ROTHWELL, WILLIAM HENRY, Captain R.N.R. (retired), 52 Woodend Drive, Jordanhill, Glasgow.

As Students.

ANDERSON, ALFRED CRAWFORD, Engineer, 47 Park View Gardens, Queen's Park, Glasgow.

DUNCAN, JAMES, Engineer, c/o Miss Campbell, 77 Hill Street, Garnethill, Glasgow.

HUNI, B.Sc., PIERRE FRANCOIS, Student in Naval Architecture, 24 Millbrae Crescent, Langside, Glasgow.

KING, ROBERT BRYCE, Ship Draughtsman, Rozelle, 41 Wallace Street, Grangemouth.

An Extraordinary General Meeting was held within the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 20th April, 1920, at 7.30 p.m.

Dr. T. Blackwood Murray occupied the chair.

The Secretary read the notice calling the meeting, and thereafter, on the motion of the President, seconded by Mr. R. T. Moore, D.Sc., the special resolutions passed at an Extraordinary General Meeting of the Institution held on 30th March, 1920, and which special resolutions are embodied in the minutes of the meeting of that date, were unanimously confirmed.

The Annual General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 20th April, 1920, at 7.45 p.m.

Dr. T. Blackwood Murray, President, occupied the Chair.

The Minutes of the Sixth General Meeting, held on 30th March, 1920, having been printed in the billet calling the meeting, were held as read, and signed by the President.

The following gentlemen were then elected as office-bearers:—For Session 1920-21—*President*, Dr. T. Blackwood Murray. For Sessions 1920-23—*Vice-Presidents*, Mr. J. Howden Hume and Mr. Harold E. Yarrow, C.B.E. *Ordinary Members of Council*, Mr. John Dickinson, Mr. Laurence MacBrayne, M.A., Mr. Noel E. Peck, Mr. N. O. Fulton, and Eng.-Capt. William Onyon, M.V.O.

The discussion on the paper entitled "A New Type of Shipyard Crane," by Mr. W. Hök, was resumed and concluded.

On the motion of the President, Mr. Hök was awarded a hearty vote of thanks for his paper.

The discussion on the paper entitled "Experiments on Riveted Joints," by Dr. James Montgomerie, was begun and concluded.

On the motion of the President, Dr. Montgomerie was awarded a hearty vote of thanks for his paper.

A paper entitled "High-Speed Craft During the War," by Mr. W. W. Marriner, was read, and the discussion thereon concluded.

On the motion of the President, Mr. Marriner was awarded a hearty vote of thanks for his paper.

The following candidates were elected:—

As Members.

Bishop, George, Engineer, 152 Market Street, Aberdeen.

Bull, Reginald Stewart, Engineer, Lenden, 26 Clendon Road, Toorak, Melbourne, Australia.

Daniels, B.Sc. (Lon.), Wilfrid, Engineer, 88 Southbrae Drive, Jordanhill, Glasgow.

Gerrard, Theodore, Engineer, 13 Edgemont Gardens, Langside, Glasgow.

Hills, Arthur Edward Castor, Engineer, 176 Langside Road, Crosshill, Glasgow.

Hutcheson, William James Fraser, Engineer, 55 West Regent Street, Glasgow.

Johnston, Henry Bannister, Engineer, 55 West Regent Street, Glasgow.

Mathie, William, Engineer, 10 White Street, Partick, Glasgow.

SMITH, HERBERT, Engineer, Sandon, Westerton, near Glasgow.

TERNEY, GERALD, Engineer, 55 West Regent Street, Glasgow.

From Associate Members.

HOLMES, B.Sc. (Lon.), JAMES, Engineer, Traisenau, Kilbarchan.

THOMSON, B.Sc., WILLIAM, Surveyor, Lloyd's Register of Shipping, 71 Fenchurch Street, London, E.C.

AS ASSOCIATE MEMBERS.

HARDIE, WILLIAM WATSON, Engineer, 11 Leslie Street, Pollokshields, Glasgow.

JOCKEL, LAURET MARSHALL, Engineer, 16 Fulton Street, Anniesland, Glasgow.

REPORT OF THE COUNCIL.

Session, 1918-1919.

The Council present their report on the affairs of the Institution for the past Session, and are pleased to record an increase in membership. Throughout the year members were still debarred from using their premises, but the ordinary work of the Institution was satisfactorily maintained.

The Roll.

The changes in membership during the year ending 30th September, 1919, are shown in the following statement:—

	Session 1917-18.	Session 1918-19.
Honorary Members - - - -	3	3
Members - - - - - -	1,073	1,107
Associate Members - - - -	346	365
Associates - - - - - -	96	90
Students - - - - - -	129	115
	1,647	1,680

The number of admissions to the register during the year was 114; while the transfers from a lower to a higher grade of membership were 20. Allowing for deletions on account of deaths and resignations, there is a gain in roll strength of 33 over that of the previous session.

Members Deceased.

With deep regret the Council place on record the names of those who have died on service.

Member.—Engineer-Lieutenant Thomas Corbett Lockie, R.N., Glasgow.

Students.—Lieutenant Charles Gattens, Glasgow; and Engine-Room Artificer John H. G. Morrison, Glasgow.

With deep regret the Council also record the following deaths:—

Members.—Archibald Campbell Adams, Paisley; William Martin Anderson, Glasgow; Henry William Andrews, Glasgow; Arthur Cannon, Birkenhead; R. Barclay Christie, Ayr; David Galbraith, Glasgow; Thos. F. Grant, Glasgow; John Inglis, LL.D., Glasgow; Robert Knox, Kilmacolm; C. R. L. Lemkes, Glasgow; David Henderson Macdonald, M.P., Uddingston; James MacKenzie, Bootle; W. A. Mackie, Glasgow; Thomas Moir, Glasgow; James Muir, Prestwick; Carl Mumme, Harrogate; Robert A. Munn, Southampton; George White Reid, Bearsden; Thomas Reid, Paisley; J. F. Robinson, London; John Shanks, Barrhead; Edmund Sharer, Newcastle-on-Tyne; Joseph Stark, Milton of Campsie; John Waddell, Glasgow; Captain James Williamson, Greenock; and John Young, Iloilo, Philippine Islands.

Associate Member.—Angus McIntyre, Glasgow.

Associates.—Edward Ernest Doddrell, Glasgow; The Right Hon. Lord Inverclyde, Renfrewshire; George A. MacBeth, Glasgow; T. Paterson Purdie, Glasgow; and James Young, Barrhead.

Work of the Session.

The Ministry of Munitions continued to occupy the Institution's premises to the end of March, and the general meetings of the Institution were held in the large lecture hall of The Royal Technical College, by the courtesy of the Governors of the College, and the Council desire to express their cordial thanks to the Governors for this privilege.

From October to April inclusive there were held seven ordinary meetings, at which the following papers were read and discussed:—

"The Air Supply to Boiler Rooms," by Richard W. Allen, C.B.E.

"Improvements in the Construction of Ships," by E. F. Spanner, R.C.N.C.

"On the Heat Transference in Surface Condensers," by Dr. Alfred W. Porter, F.R.S.

"The Stresses in the Rim and Arms of a Fly-wheel Rotating at Constant Speed," by Prof. John G. Longbottom, A.R.C.Sc.

"Stability of Ships," by George Nicol.

"Speed, Dimensions, and Form of Cargo Vessels," by G. S. Baker, O.B.E., and J. L. Kent.

"Stress Lines in Steel after Permanent Deformation," by Dr. Andrew McCance, A.R.S.M.

"Design and Construction of Flying Boats," by Captain David Nicolson.

The question of the training of apprentices, both educational and vocational, is being considered by a committee, appointed by the Council, under the chairmanship of Mr. Norman O. Fulton. In this connection, the policy of the Council will be regulated by the Committee's findings, which will be embodied in a report and probably issued on an early date.

The "James Watt" Anniversary Dinner was held in the Grosvenor Restaurant, Glasgow, on Friday evening, 7th March, 1919. Mr. W. W. Lackie presided over the meeting, which numbered 330.

Students' Section.

The meetings of the Students' Section were again suspended. The Council deplore the losses which the section sustained through the drastic operation of war, and deeply sympathise with the relatives of those who lost their lives in the service of King and Country. With a return to more normal conditions and the reoccupation of the Institution's premises, after reconditioning by the Public Works Department, the Council hope that the reorganisation of the section will speedily follow. As the old condition of things has passed away, the section must in future be unlike what it was before; it must take on a new form of life in which social fellowship and well-regulated recreation each has a share. These features the Council desire to see developed by the students through their own office-bearers.

Honours Conferred upon Members.

The Council take this opportunity of offering their congratulations to the recipients of the following honours:—

In recognition of the outstanding services rendered to the Empire in his capacity of Director of Munitions in Scotland during the war, Mr. Fred Lobnitz has been admitted a burgess, freeman, and guild brother of the Royal Burgh of Renfrew, his native town; he has also been appointed an Officer of the Legion of Honour. Mr. Charles H. Luke has received the distinction of Chevalier of the Legion of Honour, and Mr. A. W. Sampson has been made a Commander of the Order of the British Empire.

James Watt Centenary Memorial.

To commemorate the centenary of the death of James Watt, the Council sanctioned a proposal to provide additional facilities in this district for the training of engineers, and to endow an additional Chair of Engineering at the Glasgow University. There can be no more fitting way of paying tribute to the memory of Watt than by providing such facilities, and for the purpose a sum of £50,000 is considered necessary. As the result of a private appeal for funds, subscriptions amounting to £22,000 have already been promised. To achieve success, the Executive Committee in charge of the scheme solicit the assistance and patronage of engineers and others throughout Scotland, and will be pleased to receive, through the Secretary of the Institution, donations from those interested and willing to help.

A Le Rhone aeroplane engine of 90 horse-power, gifted to the Institution by Mr. Richard W. Allen, C.B.E., has been placed in the reading-room. This engine, which was invented by Mons. Verdi, of Paris, has nine cylinders, and runs at from 1,200 to 1,300 revolutions per minute. Upon the outbreak of war its manufacture in large numbers was undertaken by

Messrs. W. H. Allen, Son & Co., of Bedford, and it was subsequently fitted in the following aeroplanes:—D.H.5, Sopwith Scout, Bristol Scout, and Avro. Nearly every part of the engine is made of steel, and it is interesting to note that it comprises not less than 1,156 separate pieces.

TREASURER'S
INCOME AND EXPENDITURE ACCOUNT
GENERAL

ORDINARY INCOME.			1918-1919.	*1917-1918.*
I. *Annual Subscriptions received—*				
Members	£1,928 0 0			
Associate Members ..	303 0 0			
Associates	130 10 0			
Students	29 0 0			
			£2,390 10 0	*£2,315 10 0*
II. *Arrears of Subscriptions recovered*			55 10 0	*88 0 0*
III. *Sales of "Transactions"*			13 7 6	*25 2 6*
IV. *Interests and Rents—*				
Interest on Deposit Receipts	47 3 1			
Interest on Clyde Trust Mortgages	54 18 5			
Interest on 6% Exchequer Bond	60 0 0			
Interest on 5% War Stock	62 10 0			
Interest on 5% National War Bonds	10 0 0			
Sundry Rents	800 0 0			
			1,034 11 6	*1,203 6 6*
V *Advertisement Receipts*			280 7 2	*229 5 3*
Deficit carried to Balance Sheet			361 9 3	.. .. ..
			£4,135 15 5	*£3,861 4 3*

STATEMENT.
FOR THE YEAR ENDING 30TH SEPTEMBER, 1919.
FUND.

ORDINARY EXPENDITURE.			1918-1919.	*1917-1918*
I. *Management Expenses*—				
Salaries	£986 3 6			
Stationery, Postages etc.	78 4 8			
Office Expenses ..	40 5 7			
Lithography ..	9 16 0			
Library Books ..	9 11 6			
Travelling Expenses	17 7 6			
Interest on Bank Account	0 4 6			
		£1,141 13 3		
II. *House Expenses*—				
Feu-duty, Taxes and Insurance ..	£700 19 8			
Caretaker and Cleaning	80 14 0			
Maintenance and Repairs	6 2 4			
Heating and Lighting ..	31 8 1			
Depreciation— Furniture and Fittings ..	50 0 0			
		869 4 1		
			£2,010 17 4	*£1,966 5 5*
III. "*Transactions*" *Expenses*—				
Printing and Binding ..		£1,030 16 4		
Do. do. to complete Vol. 62 (Est.)		772 10 0		
Postages		98 15 9		
Reporting		14 6 0		
Delivery of Volume (Est.) ..		30 0 0		
			1,946 8 1	*1,756 0 10*
EXTRAORDINARY EXPENDITURE.				
Income Tax on Surplus Rents, 1916-18 ..			178 10 0	*18 1 6*
Surplus carried to Balance Sheet			.. .. ..	*120 16 6*
			£4,135 15 5	*£3,861 4 3*

BALANCE SHEET, AS AT

LIABILITIES.			As at 30th Sept., 1919.	*As at 30th Sept., 1918.*
I. *General Capital Account*—				
As at 1st October, 1918	£31,843 17 2			
Entry Money	77 0 0			
	£31,920 17 2			
Less Deficit on Revenue A/c	361 9 3			
			£31,559 7 11	*£31,843 17 2*
II. *Life Members' Subscriptions*			1,130 0 0	*1,055 0 0*
III. *Feu Duty and Taxes accrued*			528 10 0	*150 0 0*
IV. *Sundry Creditors*			2,960 11 8	*786 19 6*
V. *Subscriptions paid in advance*			83 10 0	*73 10 0*
VI. *Social Fund*			32 8 3	*31 11 10*
VII. *Medal Funds*—				
Marine Engineering—				
Balance as at 1st Oct., 1918	£814 4 1			
Interest received	27 15 9			
		£841 19 10		
Railway Engineering—				
Balance as at 1st Oct., 1918	£543 18 9			
Interest received	18 11 4			
		£562 10 1		
Students—				
Balance as at 1st Oct., 1918	£321 16 2			
Interest received	10 19 9			
Grant from "Buchanan and Ewing Bequest,"	50 0 0			
		£382 15 11		
			1,787 5 10	*1,679 19 0*
			£38,081 13 8	*£35,620 17 6*

30TH SEPTEMBER, 1919.

ASSETS.			As at 30th Sept., 1919.	*As at 30th Sept, 1918.*
I. *Buildings Account*			£27,442 19 7	*£27,442 19 7*
II. *Furniture and Fittings* ..	£800 0 0			
Less Depreciation ..	50 0 0			
			750 0 0	*800 0 0*
III. *Books in Library*—				
Valued at, say			500 0 0	*500 0 0*
IV. *Investment Account*—				
Clyde Trust Mortgages ..	£1,700 0 0			
6% Exchequer Bond ..	1 000 0 0			
5% War Stock (1929-1947) ..	1,187 10 0			
5% National War Bonds ..	200 0 0			
			4,087 10 0	*4,087 10 0*
V. *Medal Funds' Investments*—				
Clyde Trust Mortgages ..	£1,200 0 0			
5% National War Bonds ..	350 0 0			
Deposit Receipt ..	164 8 6			
			1,714 8 6	*1,617 14 0*
NOTE.—Balance of £72 17s 4d since lodged on Deposit Receipt.				
VI. *Arrears of Subscriptions*—				
Session 1918-1919—				
Members	£62 0 0			
Associate Members	13 0 0			
Associates	3 0 0			
Students	4 0 0			
	82 0 0			
Previous Sessions—				
Members .. £34 0 0				
Associate Members 4 0 0				
Associates .. 1 10 0				
Students .. 0 10 0				
	40 0 0			
Total	£122 0 0			
Valued at, say	.. ..		50 0 0	*50 0 0*
VII. *Rents, interests, etc., accrued*	.. ..		762 4 10	*617 8 1*
VIII. *Cash*—				
In Bank on D/R.	£2,639 13 0			
„ Current Account ..	135 1 5			
	£2774 14 5			
Less due Secretary	3 8			
			2,774 10 9	*505 5 10*
			£38,081 13 8	*£35,620 17 6*

Glasgow, *10th November, 1919.*—Audited and certified correct.

DAVID BLACK, C.A., *Auditor.*

REPORT OF THE LIBRARY COMMITTEE.

During the Session the accessions to the Library were 169 volumes and pamphlets. Of these 14 were Board of Trade Reports on Boiler and Steam-pipe Explosions; 32 volumes and pamphlets by donation; 103 volumes and pamphlets by exchange; and 20 volumes by purchase.

In addition to the books consulted in the Library and Reading-room, 954 were loaned to 594 borrowers. This number included 600 complete works, 89 volumes of transactions, proceedings of technical institutions, etc., and 265 periodicals, etc.

The Institution possesses a set of Abridgments of Specifications of Patents from the year 1617, and files of the principal periodicals are kept.

The Library Committee will be pleased to receive gifts of technical books, etc., to be preserved in the Library for reference.

LIBRARY ACCESSIONS.

By Donation.

British Engineers' Association: Official Directory. London. 1918-19. From the Association.

Engineering Standards Committee Publications:—
Thirteenth Report on Work Accomplished. 1917-19. From the Committee.

Dempsey, G. D., and Clark, D. K. The Locomotive Engine. London. 1879.—Dempsey, G. D. Atlas of Engravings on the Rudimentary Treatise on Locomotive Engines. London. 1859.—Fleming, J. A. Centenary of the Electric Current. London. 1899.—Goodeve, T. M. Gas Engines. London. 1889.—Holmes, G. C. V. Marine Engines and Boilers. London. 1889.—Locomotive History. (2 vols.) The illustrations, numbering over 1,200, were collected by the donor during a period of 36 years.—Murray, R. Marine Engines. 3rd ed. London. 1858.—

Napier, J. Electro-Metallurgy. 3rd ed. London. 1857.—Thomson, T. Heat and Electricity. Edinburgh. 1830.—Wilson, R. The Screw Propeller. 2nd ed. London. 1880. From Mr. J. H. Alexander.

Haier, F. Dampfkessel-Feuerungen zar Erzielung einer möglichst rauchfreien Verbreunung. Berlin. 1899.—Southern, T. Bergen's Marine Engineer. 11th ed. North Shields.—Tolle, M. Die Regelung der Kraftmaschinen. Berlin. 1909. From Miss Doddrell.

Heidenreich, E. L. Engineers' Pocket Book of Reinforced Concrete. New York. 1909.—Jones, F. D. Turning and Boring. New York. 1915.—Thomson, J. H., and Redwood, Sir B. Handbook on Petroleum. 2nd ed. London. 1906. From Mr. J. R. Chalmers.

Kempe, H. R. *ed.* The Engineer's Year Book for 1919. London. 1919. From the Editor.

Love, A. E. H. Mathematical Theory of Elasticity. Cambridge. 1906.—Gillespie, W. M. Surveying. (2 vols.). New York. 1910.—Waddell, J. A. L. Bridge Engineering. (2 vols.). New York. 1916. From Mr. J. Waddell.

Martin, H. M. New Theory on the Steam Turbine. London. 1918. *pph.* From the Author.

Ministry of Munitions of War.—Scottish Advisory Committee on Iron and Steel Production. Tables of Analysis by Prof. T. Gray. 2 copies. Glasgow. 1918. From the Committee.

Motor Ship and Motor Boat. Vol. XXIX. London. 1918. From the Proprietors.

Richardson, J. The Semi-Diesel Oil Engine. London. 1918. From the Author.

Sothern, J. W. M. Marine Engine Indicator Cards. 2nd ed. Glasgow. 1918. From the Author.

University of Glasgow. Calendar, 1919-20. Glasgow. 1919. From the University.

University of Liverpool. Calendar, 1919-20. Liverpool. 1919. From the University.

The Committee desire to cordially thank the donors of books and pamphlets to the Library.

By Purchase.

Babcock, G. D. The Taylor System in Franklin Management. London. 1917.

Bullens, D. K. Steel and its Heat Treatment. New York. 1916.

Cain, J. C. The Manufacture of Intermediate Products for Dyes. London. 1918.

Church, A. H. The Science and Practice of Management. New York. 1914.

Croft, T. Electrical Machinery. New York. 1917.
Franklin, B. A. Experiences in Efficiency. New York. 1915.
Gibson, G. A. Treatise on Graphics. London. 1905.
Hool, G. A., and Johnson, N. C. Concrete Engineers' Handbook. New York. 1918.
Jeans, J. H. The Mathematical Theory of Electricity and Magnetism. 3rd ed. Cambridge. 1915.
Morley, A. Strength of Materials. 3rd ed. London. 1913.
Nicol, G. Ship Construction and Calculations. 2nd ed. Glasgow. 1912.
Perry, H. Theories of Energy. New York. 1918.
Ramsey, A. S. Elementary Geometrical Optics. London. 1914.
Rayleigh, Lord. The Theory of Sound. Vols. I. and II. London. 1896.
Shepard, G. H. The Application of Efficiency Principles. New York. 1917.
Spooner, H. J. Wealth from Waste. London. 1918.
Tyndall, J. Sound. 5th ed. London. 1913.
Watson, T. H. A Manual on Laying-Off Iron, Steel, and Composite Vessels. 3rd ed. New York. 1917.
Who's Who. London. 1919.

The Institution Exchanges Transactions with the Following Societies, Etc.:—

Aberdeen Association of Civil Engineers, Aberdeen.
Aeronautical Society of Great Britain, London.
American Institute of Electrical Engineers, New York.
American Institute of Mining Engineers, New York.
American Philosophical Society, Philadelphia.
American Society of Civil Engineers, New York.
American Society of Mechanical Engineers, New York.
American Society of Naval Engineers, Washington.
Association des Ingénieurs sortis des Écoles Spéciales de Gand, Gand.
Association Technique, Paris.
Barrow and District Association of Engineers, Barrow.
British Association for the Advancement of Science, London.
British Corporation for the Survey and Registry of Shipping, Glasgow.
Bureau of Steam Engineering, Navy Department, Washington.
Bureau Veritas International Register of Shipping, Paris.
Chemical, Metallurgical, and Mining Society of South Africa, Johannesburg.
Collegio Degli Ingegneri e Architetti in Palermo, Palermo.
Collegio Degli Ingegneri Navali e Meccanici in Italia, Genova.
Corps of Engineers, United States Army, Washington.
École Polytechnique, Paris.
Engineering Association of New South Wales, Sydney.
Engineering Institute of Canada, Montreal.

Engineering Society of the School of Practical Science, Toronto.
Franklin Institute, Philadelphia.
Incorporated Institution of Automobile Engineers, London.
Institute of Marine Engineers, London.
Institute of Metals, London.
Institute of Railway Signal Engineers, Derby.
Institution of Civil Engineers, London.
Institution of Civil Engineers of Ireland, Dublin.
Institution of Electrical Engineers, London.
Institution of Gas Engineers, London.
Institution of Mechanical Engineers, London.
Institution of Mining Engineers, London.
Institution of Municipal Engineers, London.
Institution of Naval Architects, London.
Iron and Steel Institute, London.
Junior Institution of Engineers, London.
Literary and Philosophical Society of Manchester, Manchester.
Liverpool Engineering Society, Liverpool.
Lloyd's Register of British and Foreign Shipping, London.
Manchester Association of Engineers, Manchester.
Massachusetts Institute of Technology, Cambridge, Mass.
Midland Institute of Mining, Civil, and Mechanical Engineers, Sheffield.
Mines Branch, Department of Mines, Ottawa.
Mining Institute of Scotland, Glasgow.
Municipal School of Technology, Manchester.
National Physical Laboratory, Teddington.
Norske Veritas Register of Shipping, Kristiania.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Northern Engineering Institute of New South Wales, Newcastle, N.S.W.
Nova Scotian Institute of Science, Halifax, N.S.
Patent Office, London.
Royal Canadian Institute, Toronto.
Royal Dublin Society, Dublin.
Royal Philosophical Society, Glasgow.
Royal Scottish Society of Arts, Edinburgh.
Royal Society of Arts, London.
Royal Society of Edinburgh, Edinburgh.
Royal United Service Institution, London.
Scientific Library, U.S. Patent Office, Washington.
Scientific Society of the Royal Technical College, Glasgow.
Smithsonian Institution, Washington.

Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Ingénieurs Civils de France, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
Society of Engineers, London.
Society of Naval Architects and Marine Engineers, New York.
South Wales Institute of Engineers, Cardiff.
University of Illinois Engineering Experiment Station, Urbana.
Victorian Institute of Engineers, Melbourne.
West of Scotland Iron and Steel Institute, Glasgow.
Western Society of Engineers, Chicago.

Weekly.

American Machinist.
Autocar.
Automotor Journal.
Canadian Machinery.
Colliery Guardian.
Contractor's Record and Municipal Engineering.
Electrical Review.
Electrician.
Engineer.
Engineering.
Engineering and Industrial Management.
Engineering Production.
English Mechanic.
Fairplay.
Flight.
Indian Engineering.
Iron and Coal Trades' Review.
Journal of Commerce (Thursday's issue).
Journal de la Marine le Yacht.
Latin American Engineering.
L'Industria: Rivista Tecnica ed Economica.
Machinery.
Machinery Market.
Madrid Cientifico.
Mechanical Engineer.
Mechanical World.
Motor Ship and Motor Boat.
Motor World.
Nature.
Nautical Gazette.
Page's Weekly.
Practical Engineer.
Railway Gazette.
Scottish Cyclist and Motor Cyclist.
Shipbuilding and Shipping Record.
Shipping World.
Syren and Shipping.
Technical Review.

Monthly.

American Marine Engineer.
Automobile Engineer.
British Engineers' Export Journal.
British Westinghouse Gazette.
Civil Engineering.
Cold Storage and Produce Review.
Concrete and Constructional Engineering.
Docks' Gazette.
Marine Engineering of Canada.
Mariner.
Merchant Service Review.
Metallurgical and Chemical Engineering.
Motor Ship.
Nautical Magazine.
Navy.
Popular Science Monthly.

Electric Railway and Tramway Journal.
Engineering Review.
Ferro-Concrete.
Gas and Oil Power.
General Electric Review.
Indian and Eastern Engineer.
Industrial Engineer.
Industrial Management.
International Marine Engineering.
Iron and Steel.
Marine Engineer.
Portefeuille Economique des Machines Revista Marittima.
Revue de L'Ingénieur et Index Technique.
Science Abstracts.
Shipbuilder.
South African Engineering.
Steamship.
Times Engineering Supplement.
Tramway and Railway World.
Wireless World.

Bi-Monthly.

The Channel.

The Library and Reading-room are open for the use of Members, Associate Members, Associates, and Students.

The Portrait Album lies in the Library for the reception of Members' Portraits. Members are requested when forwarding Portraits to attach their Signatures to the bottom of Carte.

The Library Committee is desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

As arranged by the Council, a Register Book for Students lies in the Library for the inspection of Members, the object being to assist Students of the Institution in finding suitable appointments.

A. L. Mellanby, D.Sc.,
Hon. Librarian and Convener.

REPORTS OF INSTITUTION'S REPRESENTATIVES ON VARIOUS BOARDS.

The Institution was represented on the following boards and committees:—

Advisory Council for the William Froude National Tank, by Mr. P. D. Ewing, C.B.E.;

Board of Governors of the Glasgow and West of Scotland Commercial College, by Prof. A. L. Mellanby, D.Sc.;

Board of Governors of the Glasgow School of Art, by Commander Laurence MacBrayne, M.A., R.N.V.R.;

Board of Governors of The Royal Technical College, Glasgow, by Mr. W. W. Lackie;

Board of Trade Consultative Committee, by Mr. John Duncan, Mr. J. Howden Hume, Mr. C. Randolph Smith, and Mr. Fred. J. Stephen, M.A.;

British Corporation Technical Committee, by Mr. W. J. Luke, C.B.E. and Sir William Rowan Thomson, K.B.E.;

British Marine Engineering Design and Construction Committee, by Mr. James Brown, C.B.E., Mr. Alexander Cleghorn, Mr. James S. Kincaid, O.B.E., and Mr. William G. Weir, O.B.E.;

Conjoint Board of Scientific Societies, by Dr. W. J. Goudie.

Engineering Committee of the Advisory Council for Scientific and Industrial Research, by Mr. James Brown, C.B.E.;

Engineering Standards Association: Sectional Committee on Machine Parts, Sub-Committee on Milling Cutters and other Small Tools, by Mr. W. G. Shanks;

Engineering Standards Association: Sectional Committee on Machine Parts, their Gauging and Nomenclature, by Dr. T. Blackwood Murray;

Engineering Training Organisation Committee, by Mr. Robert Robertson, B.Sc.;

Lloyd's Technical Committee, by Mr. James Brown, C.B.E., Mr. Alexander Cleghorn, Mr. James Fullerton, and Mr. William Millar, O.B.E.;

Nomenclature of Alloys Committee, by Mr. Alexander Cleghorn; and

Ship Electrical Equipment Committee, by Mr. James Lowson.

William Froude National Tank.

Throughout the year there was a steady and increasing demand for model tests from private firms, and at present members of the staff are busily engaged on this work. Another complete set of experiments was carried out on forms of standard ships for the Controller-General of Merchant Shipbuilding. The total number of forms tested from 1st April, 1918, to 14th February, 1919, was 39.

Aeronautical work was continued, and a large advance made in connection with the design of flying boats.

Two papers were read by members of the tank staff. One by Mr. Baker and Mr. Kent relative to the speed, dimensions, and form of cargo vessels was read at the February meeting of the Institution this Session, and a second by Mr. Kent, giving the results of a very large number of experiments on the effect of beam upon the resistance of ships, was read at the spring meeting of the Institution of Naval Architects this year.

Glasgow and West of Scotland Commercial College.

During the session the number of students attending the classes in book-keeping and accounting, secretarial work, and modern languages was 911, of which number 182 students were enrolled in the spring for the special intensive course arranged for demobilised officers and men. As was the case in the previous session, there was a greater percentage of women students enrolled than men.

For the next session a number of the classes suspended during the war have been reincluded in the curriculum, and the total enrolments for all departments of the college promise to be greater than those of any other session in its history.

Glasgow School of Art.

The school is the central art institution for Glasgow and the West of Scotland. Complete courses of study are pro-

vided in the subjects of drawing and painting, modelling and sculpture, design and decorative art and architecture, and the various art crafts.

The number of students attending the school during the session was 742, as compared with 615 for the previous session.

Maintenance bursaries for next session to the amount of £250 were awarded by the governors, authorised by the Scotch Education Department, and bursaries have also been granted by the following bodies:—The Haldane Trust, The Carnegie Trust, The Robert Hart Trust, The Glasgow Education Authority, The City Educational Endowments Board, and the Highland Society.

The continuation classes of the Education Authorities are affiliated to the school, and the lending museum is now participated in by 70 schools. The school has undertaken to train disabled men, no longer fit for their pre-war occupation, in such suitable crafts as they may have an aptitude for and may desire to follow. A number of such men are already in attendance at the school.

The Royal Technical College, Glasgow.

Despite many difficulties, the college was able to offer nearly its full curriculum, but the effects of the war were evident in the reduced number of students enrolled at the beginning of the session. After the armistice, however, returned soldiers joined the college in considerable numbers for " refresher " courses in preparation for a full course of study next session. The day students numbered 981, and the evening students 2,178.

The enrolment of regular day students for the new session is already far beyond any preious records, and with great regret the Governors will be obliged to reject the applications of a large number of day students and some hundreds of evening students.

To assist in meeting the extraordinary demands now being made upon the college, and particularly to provide for scientific research in relation to the local industries, a new Development Fund is being subscribed, and now reaches nearly £40,000. A sum of £100,000 will be necessary to enable the college to make reasonably adequate arrangements for this essential feature of its work if it is to give the industries the valuable services of which it is capable. It is noteworthy that the largest donations to the new fund have been made by members of the governing body and by the friends who are best informed regarding its work.

The Roll of Service contains 3,105 names, and of these 607 have given their lives to the cause of their country. The honours awarded include three Victoria crosses, 317 orders and British decorations, 193 "mentions," and 49 awards from 11 of the allies. It is proposed to erect a war memorial in the entrance hall, the cost being met by members and students of the college.

Board of Trade Consultative Committee.

The Committee were mainly engaged in dealing with questions on varied subjects, all arising out of the following points of complaint of departmental procedure on the part of the Board of Trade, namely:—

1. That the Department do not consult shipbuilders through this Committee or any other representative body of builders on all occasions when contemplating changes in their regulations or instructions to surveyors.
2. That when changes are made, the system of the Department for issuing and distributing prints is very inadequate, and does not ensure prints reaching the hands of builders as early as they should.

3. That the notice given for new regulations coming into operation is invariably too short.

Should the continued representations of the Committee on these points not meet with more recognition than has yet obtained, the Committee will consider the advisability of arranging for questions being put in Parliament with the object of effecting some improvement in departmental methods.

Another subject engaging the attention of the Committee is that of the rules for arriving at the net register tonnage of vessels. The present rules are not framed so that the best possible advantage can be gained by economies of space which may arise by the use of modern forms of propelling machinery. The views of a number of leading shipbuilding firms have been obtained, and are under the consideration of the Committee with a view to deciding what steps had best be taken to obtain a revision of the rules.

The British Corporation Technical Committee.

The work of this Committee included the preparation and issue of rules for the construction of wood ships, to which the society's classification is now extended, as well as the revision of the rules for steel ships, boilers, steam engines, and internal combustion engines. The work of standardising the rules for boiler construction, which was initiated by The British Marine Engineering Design and Construction Committee, has made such progress that it is hoped the classification societies and the Board of Trade will soon agree upon rules.

The technical work in connection with the Government programme of shipbuilding was being, if possible, intensified up to the armistice period, but has recently been swinging back to the consideration of commercial ships of modern design.

British Marine Engineering Design and Construction Committee.

Frequent meetings of the Committee were held in connection with the unification of the rules of the Board of Trade and of the classification societies relating to marine engines and boilers.

The work in connection with boilers was completed, and the results published in pamphlet form. The recommendations of the Committee have been largely adopted by the registration societies, while the Board of Trade issued a circular, No. 1,600, dated January, 1919, of instructions to their surveyors, embodying a number of recommendations and modified rules of the Committee. This circular states that the Board's rules for the construction of steel boilers are being considered with a view to certain amendments being made, but that in the meantime boilers constructed to the modified rules embodied in this circular will be accepted.

The registration societies are also, in the meantime, passing boilers constructed to the new rules.

The deliberations of the Committee on the unification of the rules relating to propeller shafting are practically complete. Draft copies of the amended rules have been printed, and will be submitted to the Board of Trade and the registration societies at an early date.

Conjoint Board of Scientific Societies.

The Conjoint Board held four meetings since October, 1918. A fifth meeting, called for 8th October, 1919, was abandoned on account of the railway strike.

The principal matters under consideration by the various committees were as follow:—

1. The Committee on Timber for Aeroplane Construction were engaged on the revision of the nomenclature of aeroplane timbers for the Royal Aeronautical Society.

2. The first report of the Adhesives Committee is in preparation, and will deal with—

(a) The working out of a method for diminishing waste in producing casein adhesives.

(b) The preparation of a new glue from a waste product.

(c) A new glue, which is not injured by boiling for 24 hours.

3. The Patent Laws Committee were engaged in drawing up a statement of the difficulties which arise in consequence of the wide differences existing between the Patent Laws of various countries.

4. The results of the conference between the Watching Committee on Education and the Council for Humanistic Studies have been embodied in a pamphlet by Sir Frederic Kenyon, which will be published shortly.

5. The Petrophysical Institute Committee had under discussion suggestions for the establishment of a British Petrophysical Institution, and submitted a comprehensive report. This report has been approved by the Board, and referred to the Executive Committee for action.

6. The Water Power Committee issued their second report, which gives valuable information regarding the water power of various parts of the British Empire.

Engineering Standards Association: Sectional Committee on Machine Parts, Their Gauging and Nomenclature.

Two interim reports on British Standard Whitworth and British Association Screw Threads and their Tolerances, C.L.(M)7270 and C.L.(M)7271 respectively, were drawn up by the Sub-Committee on Screw Threads and published. A report, No. 95, giving tables of corrections to effective

diameter required to compensate pitch and angle errors combined is nearly ready for publication.

Report No. 57 on Heads for Small Screws is under revision, and the new edition is nearly completed.

A delegation of the American National Screw Thread Commission, appointed by Congress in October, 1918, to investigate the question of screw thread standardisation in the United States, visited England during the latter part of July and August. Informal conferences were held at which various difficulties in connection with the Anglo-American agreement on screw threads were thoroughly discussed. As the meetings were of an informal nature no definite steps were taken, but it is hoped that the discussion will bear fruit, in so far that many obscure points regarding the practice in either country were cleared up, and a more complete knowledge gained of the work done on either side of the Atlantic.

A conference on limit gauges, attended by a large number of manufacturers, was held in April last, at which a recommendation was made that a new sectionl committee be appointed to deal with the subject in a more comprehensive manner than heretofore, and this recommendation was subsequently approved by the Committee of the British Engineering Standards Association.

The four panels appointed by the Sub-Committee on Milling Cutters and Small Tools in June, 1918, to deal with the standardisation of form relieved cutters, non-relieved cutters, end mills, and reamers, finished their work in the spring of this year, and their reports have been approved by the sub-committee.

Three further panels were appointed to deal with the subjects of twist drills, grinding wheels, and taps and dies. The latter is the original tap panel of the Sub-Committee on Screw Threads, which was reorganised and transferred to the Sub-Committee on Milling Cutters in May, 1919.

Circular saws have also to be taken up by one of the panels with a view to including the subject eventually in the small tools specification, together with the three last-named subjects.

The reports Nos. 32 and 35, on Steel and Copper Alloy Bars respectively, for use in automatic machines, are under revision both as regards the number of standard sizes and the manufacturing limits to be allowed thereon.

A report on Copper-Alloy Fittings for Domestic Work, which had been in abeyance during the war, is being proceeded with, and it is anticipated that it will be passed very shortly.

Lloyd's Technical Committee.

The business under the consideration of Lloyd's Technical Committee was the anchor and chain equipment for merchant ships, bringing this back to pre-war requirements; hand and Downton pumps; cement in the bottoms of merchant ships; and ceiling and cargo battens. On account of the shortage of timber the latter were dispensed with in 1917. Where timber can be obtained, cargo battens are to be fitted in accordance with pre-war practice. A number of other matters were discussed, but remain in abeyance.

Electrical Equipment of Ships.

This Committee, appointed by the Institution of Electrical Engineers, comprising representatives from the Board of Trade, Lloyd's Register of Shipping, the British Corporation for the Survey and Registry of Shipping, the Institution of Engineers and Shipbuilders in Scotland, the Institution of Naval Architects, the North-East Coast Institution of Engineers and Shipbuilders, electrical contractors, fire-insurance offices and others, under the chairmanship of Mr. C. H. Wordingham, C.B.E., late Director of Electrical Engineering at the Admiralty, have now completed the regulations for the electrical equipment of ships.

The regulations have been adopted by the Council of the Institution of Electrical Engineers, and are now published in handy pocket form at a cost of 2s. 6d. net. Those interested in the electrical equipment of ships will find in these regulations the latest and best standard electrical practice, as adapted to different types of mercantile marine vessels.

A copy of the regulations can now be seen in the library of the Institution.

REPORT OF THE COMMITTEE APPOINTED BY THE COUNCIL OF THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND ON ENGINEERING TRAINING.

INTRODUCTION.

A Committee appointed by the Council of the Institution of Engineers and Shipbuilders in Scotland on 19th March, 1918, "to consider the question of engineering training," submitted the following recommendation in November, 1918:—

"That the Council be advised to set up a Standing Committee of the Institution to deal with Engineering Training, to consider all questions relating thereto, and with power to enter into consultation with the Local Education Authorities on all matters affecting the education and training of engineers, and to report from time to time."

The Council accepted this recommendation, and a Committee was appointed on 21st January, 1919, comprising the following members of the Institution, with power to co-opt:—

Mr. Norman O. Fulton, Chairman;
Mr. James Brown, C.B.E.;
Mr. R. A. McLaren, O.B.E.;
Mr. N. J. Maclean, B.Sc.;
Prof. A. L. Mellanby, D.Sc.;
Mr. James Richardson, B.Sc.;

Mr. Robert Robertson, B.Sc.; and
Mr. W. G. Weir, O.B.E.

Subsequently Dr. G. C. Cossar;
Prof. G. A. Gibson, M.A.;
Dr. H. F. Stockdale; and
Mr. J. H. A. McIntyre, Member of the Institution,

were added to the Committee.

In September, 1919, Dr. Cossar resigned, and his place was taken by Mr. M. L. Simpson, President of the West of Scotland Iron and Steel Institute.

Weekly meetings were held, with occasional intervals, from April to October, 1919, and from the first the Committee decided to confine their attention more particularly in the meantime to questions relating to boys leaving school at the age of 15 with a general education not beyond the stage of the Intermediate Certificate of the Scottish Education Department. These boys constitute the rank and file of the engineering industry, forming at least 80 per cent. of the whole number employed in it. Their training and education will have to be modified in view of the new conditions laid down by the Education (Scotland) Act, 1918. It is appropriate, therefore, at this time that, in reviewing the question of the education and training of those engaged in the engineering industry, attention in detail should be devoted in the first case to the large numbers who make up the rank and file. Education and Workshop Training are closely interlinked, and in any complete scheme both must be provided for, so that each will properly supplement the other.

The Committee, therefore, prepared the following Report, supplemented by a series of Appendices in which are set out in greater detail some of the matters referred to in general terms in the Report. It was felt that, for the sake of clearness and emphasis, the Report itself should be kept as

short and condensed as possible, but that it should be supported by elaboration where necessary in the form adopted.

The Committee corresponded with and have been recognised by the following representative bodies associated with the engineering industry:—

North-West Engineering Trades Employers' Association,

The Scottish Employers' Federation of Iron and Steel Founders,

The Clyde Shipbuilders' Association,

West of Scotland Iron and Steel Institute,

The Engineering and the National Employers' Federations, and
The Shipbuilding Employers' Federation,
} Through the North-West Engineering Trades Employers' Association,

and with the Education Authorities of Glasgow and Dumbartonshire.

Attention is drawn to Section 15 (3) of the Education (Scotland) Act, 1918, in which it is laid down that, "It shall be the duty of Education Authorities to communicate and co-operate with Associations or Committees of Employers, etc.," and it is suggested that the Institution should endeavour to arrange—with the concurrence of Employers' Associations—that the Committee should represent employers in Scotland under the Act.

REPORT.

The Report is submitted to the Council of the Institution of Engineers and Shipbuilders in Scotland as the unanimous opinion of the members of the Committee on the subject dealt with, and it is hoped that it will prove of value to the members of the Institution in their consideration of this most important question.

Sections.

(1) School Curricula.
(2) The Age of commencing Employment and Apprenticeship.
(3) Indentures, Agreements, and Regulations.
(4) Duration of Apprenticeship.
(5) Workshop Training.
(6) Apprentice Supervisors or Masters.
(7) Rewards for Proficiency.
(8) Day Continuation Class Curricula.
(9) Day Continuation Class Hours and Class Rooms.
(10) Day Continuation Class Teachers.
(11) Voluntary Evening Classes.
(12) Employment Exchanges.

(1) School Curricula.

The question of specialised school education for boys who intend to enter the engineering industry was very fully discussed, and the following aspects of it considered:—

Should such education begin at the age of 12 or 13; should it be given in buildings or class rooms set apart for the purpose; should it be confined to subjects specially related to the work to be taken up after leaving school; should it be given by

teachers specially trained; and should it include an increased proportion of manual training?

The present curriculum for the Intermediate certificate of the Scottish Education Department provides a sound general education suitable for boys intending to enter the engineering industry. For such boys special importance should be attached to mathematics, practical elementary science, geometrical drawing (solid), and some form of manual training. The stage to be arrived at in these different subjects is indicated in Appendix I.

For many boys, forming an important fraction of the total number, a general education on these lines would prove to be too theoretical in character, and would demand an aptitude for study quite definitely beyond their capacity; they are temperamentally disinclined for book study, and may have been brought up amidst home surroundings hardly conducive to studious work. It is very desirable to provide for these boys, between the ages of 12 and 15, a distinct and definite course of school training which, while continuing the ordinary subjects, should be to a greater extent along practical and manual lines. Some notes on a syllabus suitable for these boys are given in Appendix II.

Such a division of boys into two groups would benefit those in each, the more studious by relieving them of the company of those who could not keep up with them in theoretical study, and the less studious by providing them with work better suited to their interest and capacity. The decision as to which course each boy should follow would have to be made about the age of 12 years, in accordance with the class teacher's report, supported by examination or other suitable test. Boys who complete either of these two regular courses, and attain to a certain standard, should receive certificates giving detailed information as to the work done. These certificates could be accepted by employers as qualifying for apprenticeship on leaving school (see Section 2).

(2) The Age of Commencing Employment and Apprenticeship.

The Committee strongly recommend that boys should enter the employment of the firm with whom they are going to train immediately on leaving school. As the school-leaving age will, under the Education (Scotland) Act, 1918, be from 15 years to 15 years and four months, the gap between this and the present usual age for starting apprenticeship, *i.e.*, 16 years, is not great, and it is felt that substantial advantages in continuity of training and education will be gained if the present unsettled period between school and apprenticeship is abolished. This continuity can only be secured by reducing the age at which apprenticeship generally starts from 16 to 15.

Those who are desirous of acquiring more advanced education (see Section 4) than will be given in school up to 15 years of age would begin their apprenticeship at a later age.

If the proposals outlined in Section (1) of this Report are adopted, employers in engaging boys should give a preference to those who hold one of the qualifying certificates in the definite courses of study as laid down in Appendices I. and II., and that such boys should begin their apprenticeship immediately they enter employment. A probationary period should be included in the scheme of apprenticeship, as is generally the case.

The commencement of apprenticeship at 15 years of age means that apprentices will become journeymen at 20 instead of 21 years of age, which is the almost universal practice at the present time. Probably little objection will be raised to this change when it is considered that such a recommendation, if carried out, would have the desirable effect of making regular apprenticeships more attractive.

(3) Indentures, Agreements, and Regulations.

In view of the greatly increased obligations laid upon employers by the Education (Scotland) Act, 1918, it is

essential that a simple form of agreement or indenture should be entered into between the firm, the boy, and the boy's parent or guardian. Such an agreement helps to emphasise the serious character of the contract of service mutually entered into at the beginning of the training period and to lessen the danger of such contracts being broken for trivial reasons. Two specimen forms for the purpose are given in Appendix III., the details of which must be modified to suit the requirements of individual firms. The first is a model form of agreement suggested by The Engineering and National Trades Employers' Federation; the second is rather simpler in character, and has been in use for several years with satisfactory results.

Employers should issue printed regulations setting forth the rules and conditions governing apprenticeship or training in their works, a copy of which should be given to the boy and to his parents before signing the agreement or indenture, so that they may make themselves familiar with these rules before entering into the contract of service.

Proper apprenticeship "lines" should be issued to each lad on completing his apprenticeship; these should be printed on stout paper or parchment, and should state in detail the record of shop work and study carried out during training. A specimen form of apprenticeship "lines" is shown in Appendix IV.

(4) Duration of Apprenticeship.

No change should be made in the present general practice of fixing the period of apprenticeship at five years. The demands of the skilled trades tend to become more exacting in the way of varied and elaborate training, and less than five years cannot be considered a long enough period within which to include all the branches to be worked at and the subjects to be studied.

It is thought, however, that a specific training, limited to

three years, for certain machine operators, and other classes of semi-skilled workers, should be adopted and recognised. Such limited periods of training are already in operation, but in an unorganised and more or less unofficial way. By organising the training with a careful regard to the object in view, better progress would be made and a better result in general obtained.

The "Sandwich System" under which apprentices spend the summer in the workshop and the winter at college should be encouraged in the case of apprentices who are able to take advantage of the higher training it offers. Those who train on this system should spend at least three and a half years in the workshop before receiving their "lines."

(5) Workshop Training.

As supplementary to the Day Continuation Classes required by the Education (Scotland) Act, 1918, employers should prepare definite courses of training for their apprentices in each of the trades, suited to the circumstances of the workshop where they are employed. These courses should be as varied as possible, and should include as many different branches of the trade as may be found practicable. The time to be spent at each of the branches should be determined beforehand. The transfer of apprentices from one branch of the work to another should not be in the departmental foreman's hands, as it inevitably involves him in a conflict between his paramount duty of maintaining output and the interest of the apprentice in being advanced through different stages of his training. This duty should be in the hands of the Apprentice Supervisor, or in cases where no Supervisor is employed, in the hands of the Manager.

In the cases of larger shops employing a number of apprentices, a preliminary training should be given in a special

department before they start work in the factory, where instruction in cleanliness, orderliness, safety, and the names and uses of ordinary tools would be given. Before leaving this department the boy should be required to reach an agreed standard of knowledge and skill. Apprentices might return to this special department for further instruction before entering any new section of the works.

In the case of exceptionally good apprentices, the variety of work during training should be extended; for instance, apprentice fitters might receive machine-shop experience.

In all works, individual instruction should be given to apprentices. In the larger shops special instructors should be appointed for this duty, while in the smaller factories instruction should be given by foremen or charge hands.

(6) Apprentice Supervisors or Masters.

The employment of Apprentice Supervisors or Masters is strongly advised, such Supervisors or Masters to be appointed as members of the staff. They should be well educated men, of firm and sterling character, and should be in sympathy with the boy's outlook and keenly interested in all his activities. If possible also they should have received some workshop training in one of the skilled trades.

The duties of Apprentice Supervisors are set out in detail in Appendix V.

(7) Rewards for Proficiency.

Rewards for proficiency undoubtedly encourage effort and act as a stimulus in a Scheme of Training, and as such are very desirable. A system of awards based on consideration of different schemes at present in operation in industrial firms is given in Appendix VI.

(8) Day Continuation Class Curricula.

If the course of education suggested in the foregoing and detailed in Appendix I. is adopted, then all the boys who take this course, and obtain the qualifying certificate, will form one group which may be termed Grade I. They will leave school at the age of 15, and immediately thereafter commence attendance at Day Continuation Classes as prescribed by the new Education Act, and will probably begin their apprenticeship about the same time. For these boys the Schedule in Appendix VII. is submitted as a suitable course of study for the three years' attendance at Day Continuation Classes, which will be compulsory when the Education (Scotland) Act, 1918, comes into force. During these three years a total time of 960 hours is available, of which it may be assumed that about 200 hours will be devoted to English and 160 hours to physical exercises, leaving 600 hours for "special instruction conducive to the efficiency of young persons in the employment in which they are engaged," Education (Scotland) Act, 1918, Section 15 (4) 6.

If the course suggested in Appendix II. is also adopted, the boys who take this course will form a second group which may be termed Grade II. They will leave school at about the age of 15, and probably enter employment in the engineering industry and commence attendance at Day Continuation Classes at about the same time. Some notes on a course of training suitable for these boys occupying the 600 hours to be devoted during the three years to special instruction are given in Appendix VIII.

It is not considered practicable to connect these two courses so that boys can pass regularly from one to the other. Boys in Grade I. who fall behind may spend part of the three years in the classes provided for Grade II. Boys in Grade II. who make specially good progress may—by supplementary attendance at evening classes, or by private study—qualify for admission to

the classes arranged for Grade I.; but such exchanges would be exceptional.

In addition to these two clearly defined Grades, there will be a number of boys attending the Day Continuation Classes, who, due to special circumstances such as leaving school at a later age, being educated at a school outside the regular system, failure to obtain a qualifying certificate, education interrupted due to sickness, etc., will not fit in exactly with either of these two courses of study. If, however, courses are arranged for these two definite Grades, with a first, second, and third year class for each Grade, instruction would be provided to suit the needs of, practically speaking, all the boys in attendance at the day classes.

(9) Day Continuation Class Hours and Class Rooms.

In view of the recent reduction of working hours in the engineering industry to 47 per week, and of Section 15, Clause 9, of the Education (Scotland) Act, 1918, which lays down that the aggregate hours of employment and attendance at continuation classes shall not exceed the permitted time under any Act of Parliament (which at present is 60 hours per week), the Committee is of opinion that part at least of the day class instruction could be given after the factory closing hour.

On the question of the Works School, or the School in the Works, the Committee felt that they could not make any specific recommendation. There are a number of such schools already at work throughout the country giving very promising results, and this number is likely to grow under the new Education Act. Local circumstances, such as the size of the works, the number of similar works in the neighbourhood, the number of boys employed, etc., must largely determine whether a Works School is practicable or desirable. The subject is discussed in detail in Appendix IX., and is commended to the attention of employers as worthy of their careful consideration.

Special schools will not be required for the Day Continua-

tion Classes, but special class rooms in the existing schools or in the new buildings to be provided under the Act will be necessary, as the furniture and equipment of the ordinary class rooms are not suitable for the requirements of boys from 15 to 18 years of age. Also, the provision of properly equipped laboratories, drawing-class rooms, and workshops will be essential to the useful conduct of these classes.

(10) Day Continuation Class Teachers.

The teachers of the Day Continuation Technical Classes should be trained specially for this work. The men who undertake to teach mathematics, science, and drawing to engineer apprentices should themselves have a practical knowledge of the work in which they are from day to day engaged, and, therefore, such teachers should have served an engineering apprenticeship or received an equivalent workshop training. Further, it is recommended that these teachers should be granted facilities by employers for returning to the workshop from time to time for short periods of practical training, so that their knowledge of shop methods might be kept up to date. Such periods of training could be arranged for immediately before or after the summer holidays.

Each teacher should hold a Degree or Diploma in Engineering Science, failing which, the minimum theoretical training should be not less than that represented by the second year course for engineers at a recognised University or Technical College, including two sessions in engineering drawing. The subject of "Methods of Teaching" could be provided for by one or more special courses under the Provincial Committees for the Training of Teachers given in the summer sessions at a University or Technical College.

(11) Voluntary Evening Classes.

During the present state of flux of industrial conditions it is difficult to define the changes which may take place

in the present system of Technical Evening Classes. Attendance is at present not compulsory, and therefore it may be concluded that many of the scholars have some aptitude and liking for study. Further, the new Day Continuation Classes up to 18 years of age, by advancing the boy's knowledge of his subject, will tend in many cases to increase his interest in further study. Therefore, the demand for evening classes will probably not die out, and it may even increase. The subjects to be taught will be influenced by the Act, while the more advanced stage reached by the boys with the help of day study will enable the evening classes to undertake higher work.

Evening instruction might be arranged on lines different from the present system of Continuation Classes. Tutorial study organised to assist the work of the day classes might prove very useful. Classes in special branches of science not covered by the regular day courses, with which in the past there has been no time to deal by means of evening study alone, could be organised in selected centres. Courses of lectures on the history of Engineering, Economics, Workshop Organisation, etc., would do much to broaden the outlook of the more thoughtful apprentices.

The boys in Grade II. will in most cases be satisfied with the technical instruction they receive during the day; but, in order that their interests in life may be broadened, suitable facilities for evening occupation should be provided, and they should be encouraged to make use of such facilities. Classes in Elementary Natural Science, Music, Arts and Crafts, and Citizenship should be organised on a wide-spread and attractive scale, so that each boy would have an opportunity of attending them.

Apart, however, from the subject of training in the technical sense, the longer leisure available, due to the reduction of the working week to 47 hours, makes a charge upon the considera-

tion of those who have at heart the well-being and progress of the boys and young men in industry; and in this connection the greatest encouragement must be given to organised recreation identified with the works with which the boys are connected in their daily lives. Reference under this heading should also be made to Section 6, where the employment of Apprentice Supervisors and the movement they represent is recommended.

Lads over 18 who wish to continue their technical education will be provided for by the courses of study at the Technical Colleges and affiliated centres. These courses will be affected by the Act, but as the boys who enter them will be better prepared for their work, the more elementary classes in certain subjects may be omitted.

No doubt a large number of the boys who have taken the Day Continuation Courses until they are 18 will not persevere with their studies beyond that age, but every encouragement should be offered to those who are willing to do so to continue attendance at classes in the cultural subjects mentioned in a preceding paragraph. For these older lads, such subjects at a more advanced stage might be taught in selected centres (on the lines of the present higher technical classes in selected schools).

(12) Employment Exchanges.

Employers are recommended to make fuller use of Employment Exchanges in engaging apprentices. Attention is drawn to the fact that these Exchanges now have special Juvenile Advisory Committees to assist boys on leaving school to choose their occupation and to find the employment best suited to their wishes and circumstances. The scope of such Committees is at present restricted by the Ministry of Labour, and more latitude may be given to them in future, depending in part upon the extent to which employers take advantage of their help.

APPENDICES.

I. Syllabus for boys (12 to 15 years of age) taking the Theoretical Course.
II. Syllabus for boys (12 to 15 years of age) taking the Practical Course.
III. Agreement of Apprenticeship.
IV. Apprenticeship "Lines."
V. Duties of Apprentice Supervisors or Masters.
VI. Rewards for Proficiency.
VII. Scheme of work for three years' course of Day Continuation Classes following syllabus laid down in Appendix I.
VIII. Notes on a three years' course of training in Day Continuation Classes following syllabus laid down in Appendix II.
IX. The School in the Works.

APPENDIX I.

Syllabus in certain subjects for Boys (12 to 15 years of age) taking the Theoretical Course.

Mathematics.

Algebra.—Including involution and evolution, simple equations in one or more unknowns, quadratic equations in one unknown, and problems involving them.

Geometry.—Including properties of the triangle, rectangle, and circle.

Graphs.—Graphs of quadratic equations and graphs of formulæ.

Trigonometry.—Including the solution of right-angled triangles, height and distance problems.

Logarithms.—Logarithms and use of tables.

Experimental Science.

Heat.—Elements of heat.

Chemistry.—Elements of chemistry.

Geometrical Drawing.

Solid Geometry.—Illustrated by models made by the pupil.

APPENDIX II.

Syllabus for Boys (12 to 15 years of age) taking the Practical Course.

English.

The teaching of English subjects (including history and geography) should be on normal lines, but should be more closely interlinked with the other work of the course. Training in composition should be given by describing the observations made and the work done in the practical classes.

Arithmetic.

This should largely be taught along with manual classes, including the use and interpretation of simple algebraic formulæ and graphs. Mensuration, weights and measures, etc., should be based on experimental work.

Manual Training.

Several hours per week should be devoted to manual training, which should include work in wood, metal, leather, plaster, etc.

Drawing.

The drawing should be related to the manual training and experimental science, and be used to confirm the arithmetic. It should include freehand, model, and simple solid geometrical drawing and sketching to scale.

Practical Science.

Experiments illustrating the elementary principles of mechanics and heat should be carried out, which should, as far as possible, be related to the work done in the manual training and drawing classes.

The object of the course should be to develop and train the observational powers, manual dexterity, capacity to make and to record simple experiments, and to draw deductions from them. Principles should be taught by experimental methods.

APPENDIX III.

Agreement of Apprenticeship.

This Agreement, made the.....day of.....One Thousand, Nine Hundred and.....years, between A. B. & Co. (hereinafter called "the Employer"), and C. D. (hereinafter called "the Apprentice"), a minor,.....years of age on the.....day of ....., One Thousand, Nine Hundred and.....years, with the special advice and consent of E. F., as witnessed by his signature as a party hereto (hereinafter called "the Guardian"), and the said E. F. as security for the due fulfilment by the Apprentice of the obligations undertaken by him.

Whereas the Apprentice has, with the consent of the Guardian, agreed to serve the Employer, and the Employer has agreed to accept him as an Apprentice, upon the conditions hereinafter specified.

Now this Agreement Witnesseth that, in consideration of the obligations hereinafter, with consent foresaid, undertaken by the Apprentice, the Employer agrees to take and receive the Apprentice as an Apprentice.....for the term of .....years, as from and after.....day of.....One Thousand, Nine Hundred and.....years, and will, provided he continues to carry on business during the said period, to the best of his knowledge, power, and ability, teach and instruct the Apprentice or cause him to be taught and instructed during the said period in the trade or occupation of.....so far as carried on by the Employer and as the capacity of the Apprentice will permit. In consideration of the foregoing obligations undertaken by the Employer, the Apprentice, with the advice

and consent foresaid binds himself Apprentice to the Employer for the said period, and binds and obliges himself that he shall be a faithful and obedient Apprentice to the Employer, and that he shall not reveal the secrets of the Employer's business nor waste, damage, spoil, destroy, or embezzle any of the goods, chattels, or property of the Employer or his customers, or willingly or knowingly permit it to be done by others, but shall and will in all respects endeavour to promote the interests of the Employer and the credit of his works to the best of his knowledge, skill, and ability, and shall not nor will at any time during the said period (except sickness make it necessary) absent himself from or willingly neglect the work or service of the Employer, or work with or for or serve any other person or persons, or engage in any trade or business, without the Employer's express consent in writing for that purpose first obtained, and shall and will during the said period observe, perform, and be subject to the conditions of employment contained in the Schedule annexed and signed as relative hereto; and the Guardian hereby binds himself as security for the due fulfilment by the Apprentice of the obligations undertaken by him. Without prejudice to his rights otherwise, the Employer reserves specifically right to suspend for a reasonable period without wages or to instantly discharge at any time without a certificate of service any Apprentice who may take part in a trade dispute or who may commit a breach of the provisions hereof or may otherwise be guilty of misconduct, of which breach and misconduct and the reasonableness of any period of suspension which may take place the Employer shall be the sole judge, and in the event of discharge any sum deposited or guaranteed by or on behalf of the Apprentice in terms of Article .....of the Schedule hereto annexed will be forfeited to the Employer.

In Witness Whereof

(Signatures.)

SCHEDULE REFERRED TO IN THE FOREGOING AGREEMENT.

Wages.—

1st year at the rate of.....per week.
2nd ,, ,, ... ,,
3rd ,, ,, ... ,,
4th ,, ,, ... ,,
5th ,, ,, ... ,,

The Apprentice shall, if required by the Employer, work piecework or other system of payment according to output, subject to his time rate of wages being guaranteed when so employed.

Overtime.—The Apprentice shall, if required, work on overtime, and shall be paid therefor at the rate of..... When the works are on short time overtime rates shall only be paid for time worked subsequent to the full week stopping time and prior to the full week starting time, unless in the case of night-shift.

Night-Shift.—The Apprentice shall, if required, and subject to the provisions of the Factory Act, 1901, or any subsequent legislation, work on night-shift, and shall be paid therefor at the rate of.....

Working Week.—.....hours shall constitute the working week, unless where the hours are temporarily reduced by the Employer, in which case if the Apprentice works the full shortened hours, for the time being, he shall be presumed to have worked a full week for the purpose of computation of the period of his apprenticeship.

Time Lost.—All lost time must at the end of each year be made up before a further year of service is held to commence, provided that (a) time lost on account of sickness, if certificate produced and the absence does not exceed four weeks in any one year; and (b) absence with leave first asked and obtained,

shall not require to be made up. For each day off without leave two days shall at the option of the Employers be wrought.

Working Conditions.—The Apprentice shall work, as required, in or away from the Employers' works, at new or old work, and with whatever employees may be selected, at the discretion of the Employer.

Works Rules.—The Apprentice shall also conform to the rules and conditions prevailing in the works from time to time, so far as applicable and not inconsistent with this Agreement.

Deposit.—As a guarantee of the fulfilment of his engagement the Apprentice shall lodge in the Employer's hands a deposit of, or give security for, the sum of £..... Said deposit may be made by one payment or by weekly contributions of..... per week.

Holidays.—The Apprentice shall be entitled to all the usual works holidays for which payment shall.....

Certificate.—On due completion of the Apprenticeship to the satisfaction of the Employer a certificate to that effect will be granted.

Technical Education.—The Apprentice shall be encouraged (given facilities) to obtain a theoretical knowledge of the branch of trade he adopts, so far as circumstances permit. Time so occupied during working hours shall.....be paid for..... shall.....be taken into account in computing the period of his apprenticeship. (Here insert particulars of any special rules relating to the Technical Education of Apprentices.)

Bonus for Good Conduct. Advancement as Reward of Merit.

(Where this is the practice, particulars might be given.)

Note.—The foregoing conditions, where not applicable, should be deleted or amended as desired. Conditions special to any firm, and not provided for above, should be added.

AGREEMENT OF APPRENTICESHIP.

An Agreement made between JOHN SMITH LIMITED of..... .....(hereafter called "the Company") of the one part, and.....(hereafter called "the Apprentice") of the other part, with the consent of his Curator, whereby it is agreed as follows:—

(1) The Company engages the Apprentice and the Apprentice agrees to serve the Company as an Apprentice..... for the term of.....years, subject to the provisions of this Agreement.

(2) The Apprentice shall, in all respects, conform to and comply with the orders and regulations given and made by the Company, and shall well and faithfully serve the Company, and shall not do or commit any waste, damage, or other injury to the property or goods of the Company, and shall not lend or part with the same to any person without the consent of the Company.

The Apprentice during his apprenticeship shall, unless sick, or given leave of absence by the Company, be punctual in commencing his work, and shall work such number of working hours of each working day as directed by the Company.

(3) The Company shall pay to the Apprentice for each hour actually worked during his apprenticeship wages at the following rates:—

For the first year, at the rate of.....per week of 47 hours.
For the second year, ,, ,, ,,
For the third year, ,, ,, ,,
For the fourth year, ,, ,, ,,
For the fifth year, ,, ,, ,,

Should the Apprentice in any year be absent from his work without leave during any of the recognised working hours, he shall work for a corresponding period at the end of such year before the advance of wages for the following year shall be

given. Time worked beyond 47 hours in any week shall be set against time lost during the year, but shall not reduce the period of Apprenticeship.

Overtime will be paid for at the usual rates.

(4) The Company, in accordance with the practice observed in the works, or in other reasonable way, shall cause the Apprentice to be instructed during the working hours in the trade to which he is apprenticed.

(5) The Apprentice, during the first six months of his apprenticeship, shall be on trial, and if during such period the Company shall be of opinion that the Apprentice does not show capabilities for the work prescribed for him, the Company shall have the right to terminate this Agreement, on giving the Apprentice one week's notice in writing.

(6) The Company shall have the right of discharging the Apprentice, and of annulling and cancelling this Agreement, for any material breach of the Covenants herein contained, or for misbehaviour, disobedience, or unfaithfulness on the part of the Apprentice towards the Company.

(7) The Company shall not be responsible to any person or persons for any debts which may be contracted by the Apprentice, and the Company shall not be in any way bound to provide the Apprentice with lodging, medical attendance, or any necessaries.

(8) The Apprentice shall deposit with the Company the sum of £.....as a guarantee of the fulfilment of this Agreement. Such deposit shall be returned to the Apprentice at the termination of the apprenticeship, if the conditions of the Agreement shall have been well and faithfully observed by the Apprentice, but if such shall not have been done, the deposit shall be forfeited to the Company. But this provision shall in no way effect the right of the Company to insist on specific implement of the contract by judicial proceedings or otherwise.

As witness the hands of the contracting parties this..... day of....., 192 .

Signed for and on behalf of the Company.
Signed by the above-named Apprentice.
Signed by the Curator of the Apprentice.

APPENDIX IV.

Apprenticeship "Lines."

To Whom It May Concern.

This is to certify that.....commenced an Apprenticeship to the trade of.....on .....and completed it to the satisfaction of the Company on.....

Signed.....Director.

Shop Record.

Department.	Months.	Progress.

Class Record.

Class.	Year.	Progress.

Remarks.

APPENDIX V.

Duties of Apprentice Supervisors or Masters.

1. *Engagement.*—To interview boys and parents, obtain references, prepare the Indenture, and submit selected applicants for final approval by foreman or manager.

2. *Education.*—To advise each Apprentice what course of study to follow that will best suit his previous education and the trade he is learning. To keep in touch with the classes provided for the Apprentices, and obtain regular reports on the attendance and progress made.

3. *Works Training.*—To prepare schemes and time-tables of work for Apprentices, and advise the works manager when any Apprentice is due a change of work under the scheme. To keep a record of work of each Apprentice. To consider complaints from and against the boys, and, in the event of threatened dismissal, to investigate the cause. To keep in touch with the boys' parents, and to visit the boys in their homes in cases of sickness, etc.

4. *Health.*—To find out before an Apprentice is engaged whether he is thought to be physically fit for the work he is to undertake. To organise first-aid arrangements, and to keep in touch with all cases of accident or sickness among the boys. To see that sanitary, washing, and drinking facilities are adequate, and that proper arrangements are made for the boys' meals.

5. *General.*—To organise schemes of thrift, indoor and outdoor games, summer camps, and to form Cadet or Brigade Companies, or Scout Troops.

APPENDIX VI.

Rewards for Proficiency.

The granting of rewards for proficiency should be based on a general Apprentice Bonus Scheme, under which marks are given at regular intervals, say quarterly, for:—

Progress at Trade.
Diligence at Work.
Progress in Class Study.
Time-Keeping.
Conduct.

Prizes should be awarded annually to the boys who take the highest places on the list, which might take the form of an increase in the rate of wages for the ensuing year, or scholarships to attend day classes at a University or Technical College, or some wider opportunity of training during apprenticeship.

Apprentices who obtain the best total record under this scheme for the five years of their training might be promoted to the drawing office or to junior staff posts in the works, or might be specially recommended for promotion to such positions with other firms.

A Suggestion Scheme is recommended as a very useful means of bringing the more ingenious and thoughtful apprentices to the notice of the firm, and as an encouragement to them in applying individual thought to their work.

APPENDIX VII.

Scheme of Work for Three Years' Course of Day Continuation Classes following the Syllabus laid down in Appendix I.

Mathematics.

(Three Years.)

Algebra.—Up to and including simultaneous quadratic equations; problems involving these equations; ratio, proportion and variation; surds, indices, logarithms.

Geometry.—Properties of triangles, parallelograms, and circles, regard being paid to intuition in proofs; similar triangles and other figures, similarity being considered as a matter of scale; numerical applications and deductions.

Trigonometry.—The fundamental ratios and formulæ for the acute angle; applications to problems; equations and identities; extension to angles greater than 90 degrees, with graphs of the functions; formulæ for the solution of triangles; the addition theorem, with applications; logarithmic solution of triangles, with applications, radian measure.

Graphs.—Applications of the straight-line graph; graphs of quadratic functions; solution of quadratic and cubic equations by straight lines and curves; adiabatic curves giving practice in logarithms; trapezoidal, mid-ordinate, and Simpson's rules for areas; integral curves, applications; some trigonometric graphs; solution of trigonometric equations.

Practical Science.

Laboratory Work with Demonstrations.

Chemistry (First Year).—Mixtures and compounds; separation; filtering and decanting; solution, crystallisation, distillation, etc.; chemistry of air, water, and combustion; the indestructibility of matter; acids, bases, and salts; studies of common substances, such as chalk, carbon, coal, iron, and sulphur, and bodies derived from these; law of constant proportion gradually developed by the quantitative exercises done throughout the course.

Properties of Matter, Heat and Light (First Year).—Use of accurate measuring instruments, determination of sensitiveness and the use of accurate balance; specific gravity; timing of pendulums; estimation of degree of accuracy obtainable.

Thermometry; determination of melting points and boiling points by thermo-junction.

Coefficients of expansion for solids, liquids, and gases.

Determination of specific heats and latent heats.

Variation of vapour pressure with temperature.

Conductivities and radiating powers.

Photometry.

Law of reflection and refraction.

Mirrors and lenses.

Mechanics (Second Year).—Displacement; velocity; acceleration.

Momentum; force; composition and resolution of forces.

Moments of forces.

Friction.

Work; energy; power; efficiency; simple machines.

Stress; strain; modulus of elasticity, simple tension.

Compression shear; simple ideas on bending.

Electricity and Magnetism (Third Year).—Electrification by friction, conduction and induction; the electrophorus; capacity and condensers; mapping out magnetic fields; law of inverse squares; comparison of the moments of magnets; magnetic effect of a current in a conductor; field due to a circular coil; use of tangent galvanometers; resistance in series and parallel; effect of shunting galvanometer; measurement of resistance; measurements of currents and electro-motive forces; primary cells.

Engineering Drawing.

(Three Years.)

Note.—Geometry should be an integral part of all the drawing classes, and interwoven throughout the session with the technical drawing, so as to produce a systematic and progressive course.

The students should be taught how to make freehand dimensioned sketches from technical examples, and directed to have sufficient information in their sketches to enable them to produce, without further reference to the model, a working drawing of the example under discussion. In the earlier stages they should dismantle the model and sketch the details, produce working detail drawings, and, later, from these detail sketches produce an assembled drawing. All technical drawings should be carefully dimensioned and made to correspond to complete working drawings.

Geometry.—Further consideration of previous work.

Pictorial and orthographic projection of planes, solids, and simple machinery details.

Solids of revolution cut by planes and by other solids of revolution.

Helix and helical surfaces.

Cams, profile and face.

Wheel teeth forms, spur, bevel, and worm.

Technical. — Making of dimensioned detail sketches of actual machinery parts—provided as models—and from these sketches preparing detail and assembled working drawings with appropriate sections.

Proportional drawing.

Weights of machinery (approximate).

Detail drawings for one type of boiler.

Tracing practice (paper and cloth).

Gearing, spur and bevel, worm and spiral.

Materials of construction.

Use of slide rule.

Naval Architecture Drawing

(Alternative to Engineering Drawing).

(Three Years.)

(See *Note* under Engineering Drawing.)

Geometry.—Geometry of ship's form; sheer draught.

Lines of shell plating.

Expansions of plating.

Bevels.

Bossing and shaft brackets.

Technical.—Details of parts of ship's structure; plans and elevations with sections.

Structural plans.

Ship mensuration; integration of areas, volumes and moments; displacement calculations; use of slide rule.

APPENDIX VIII.

NOTES ON A THREE YEARS' COURSE OF TRAINING IN DAY CONTINUATION CLASSES FOLLOWING THE SYLLABUS LAID DOWN IN APPENDIX II.

English.—Generally as indicated in Appendix II., but on more advanced lines.

Arithmetic.—The whole subject should be reviewed in the light of the boy's occupation, examples used being based on the work to be done in the Manual Training, Drawing, and Science Classes.

Manual Training.—This should not be vocational in character; the boy should not be taught any definite operation carried on in the workshop where he is employed. The training should be given in a suitably equipped workroom or laboratory where the properties of the different materials could be studied and manual work carried on in wood, metal, plaster, etc. It should be directed to develop the boy's capacity for producing an accurate result, and for observing the differences in qualities of materials. It should also add to his manual skill and adaptability by aiding him to work in other materials than those he is learning to be familiar with in the workshop.

Drawing.—The drawing taught should include freehand, model, and solid geometrical. It should be carried on in a proper drawing room with large boards and to a large scale. An element of physical activity must enter into the teaching for this class of boy; if he is asked to crouch over a small board, and to do accurate work on a small scale, he will quickly tire of the task and refuse to work at it. He should draw what he makes in the Manual Training Class, and make there what he draws.

Practical Science.—Generally as in Appendix II., but on more advanced lines. The training should be directed to develop the boy's capacity for making and noting down definite experiments, sketching the apparatus used, and clearly describing what he

has done. The work should be related to the Manual Training Class by making there apparatus to be used for the experiments, and by determining in the Science Class the values to be attached to the general observations made in the Manual Class.

APPENDIX IX.

The School in the Works.

The School in the Works (or the Works School) has been a recognised part of the factory organisation in the case of a few firms for many years past, and in the case of an increasing number during recent years. The coming into force of the Education Act will involve changes in aim, in subjects taught and in the staff in most of these schools; but there is no reason to suppose that the advantages which have led to their being started in the past will disappear under the Act, and therefore it may be expected that they will still be carried on where they already exist, and that new schools will be opened when the circumstances are favourable to them.

It can be argued that such classes are a distraction to the employer from his proper function as a manufacturer; that they tend to provide for the boy a too narrowly vocational training; that the atmosphere of the factory with its noise and dirt is hostile to educational effort; and that the equipment of such schools could not be arranged on such complete and thorough lines as in a school serving a whole district without involving either the employer or the Education Authority in undue expense. As against these possible drawbacks there are some important advantages which the School in the Works may offer over the district school. Many of the boys attending Day Continuation Classes, especially those of 16 and 17 years of age, will not be naturally fond of book study, but will be keenly interested in the work of their trade. It is possible in the Works School to appeal to this practical interest without lessening the educational value of the subjects taught, and

by co-relating the class study with the factory work to reap the full benefits of the Day Continuation Classes; whereas in the general purpose school such a connection between practical trade work and study cannot be established or maintained.

Further, discipline will be more easily kept among boys used to working together within the authority of their factory; it will be very difficult indeed to ensure a reasonable standard of discipline in some of the classes at the district schools; also time will be saved in going from school to work and work to school.

OBITUARY.

Honorary Member.

Admiral-of-the-Fleet Lord Fisher of Kilverstone died in London on 10th July, 1920, after an operation for a serious internal malady.

John Arbuthnot Fisher was born on 25th January, 1841, at Rambodde, in Ceylon. His father, Captain W. Fisher, of the 78th Highlanders and 95th Foot, resided for many years in that eastern colony while serving as aide-de-camp to the Governor, Sir Wilmot Horton, and to General Sir Robert Arbuthnot, Lord Fisher's godfather.

At the age of 13 young Fisher entered the Navy just in time to serve on board the "Calcutta" in the Baltic Fleet during the war with Russia. He next served in the "Highflyer," "Chesapeake," and "Furious" during the China war, and was present at the capture of Canton and the attack on the Peiho Forts, receiving the China Medal with the Canton and Taku clasps. In passing for lieutenant, he won the Beaufort Testimonial, and was confirmed in the rank 11 months after being made a mate, on 4th November, 1860. He joined the "Warrior" as gunnery lieutenant in 1863, and in 1866 was appointed to the staff of the "Excellent," being advanced to commander in August, 1869. Promoted captain in 1874, he continued on instructional and experimental torpedo work until 1876, and then commanded successively the "Bellerophon," "Hercules," and "Pallas" in North America and the Mediterranean. Later he was appointed to the "Inflexible," then the biggest and most heavily armed ship in the Navy, and commanded her at the bombardment of Alexandria in 1882.

During the Egyptian operations of that period, he fitted out the " armoured train " and commanded it in several skirmishes with Arabi's troops, receiving for these services the C.B. and the British and Egyptian Medals.

In 1886 Fisher was appointed Director of Naval Ordnance and Torpedoes, retaining that office until 1891, when, having attained flag-rank in 1890, he was appointed Admiral-Superintendent of Portsmouth Dockyard. In 1892 he became Comptroller of the Navy, and in that capacity served for five and a half years. He was made a K.C.B. in 1894, and promoted to the rank of vice-admiral in 1896. Shortly afterwards he hoisted his flag for the first time afloat in the " Renown," to take command of the North American and West Indies Station.

In 1899 he took over the Mediterranean Command, and held it until the summer of 1902, having attained by seniority the rank of full admiral in 1901. On relinquishing this post he became Second Sea Lord of the Admiralty, and received the G.C.B. at the same time. It was then he introduced the scheme of common entry at an early age, and common training up to the point of specialisation for all executive, engineer, and marine officers. Sir John Fisher strove hard to raise the status of engineer officers, and was responsible for founding the Osborne School, where all cadets enjoyed the same training, which was largely engineering in character. In 1903 he hoisted his flag as Commander-in-Chief at Portsmouth, and on Trafalgar Day, 1904, he was sworn at Whitehall as First Sea Lord of the Admiralty, his tenure of this post extending over a period of five years, during which time his attention was chiefly devoted to reforms in connection with the administration, organisation, equipment, and disposition of the Royal Navy. Chief among these reforms was the initiation of what is known as the " Nucleus Crew System," whereby the whole sea-going fleet was rendered as ready for war as was compatible with peace conditions. Associated with this system also was the elimination of ships of doubtful fighting value.

Another notable feature of the new policy was the introduction of the " Dreadnought " type of capital ship, in which big guns and speed were the leading factors. He rescued the Navy from its dependence on the War Office for its guns, and was largely responsible for the introduction into the Navy of the Kelvin compass, the water-tube boiler operated with oil fuel, and the steam turbine. He was also the first to realise that the submarine was really the weapon of the stronger navy.

In 1904 Sir John Fisher was appointed by King Edward VII first and principal Aide-de-camp to His Majesty, and in the next year received the Order of Merit and was made an Admiral of the Fleet. He was created a G.C.V.O. in 1908, and on King Edward's last birthday—9th November, 1909—was raised to the peerage as Baron Fisher of Kilverstone. About three months later he resigned the office of First Sea Lord of the Admiralty.

In 1912 he wrote enthusiastically of a new type of warship with a target 33 per cent. less than any previous vessel, without masts, funnels, and smokeless, to carry 5,000 tons of oil, enough to take her round the world without refuelling. Shortly after the outbreak of war he returned to the Admiralty, but remained there only a few months, during which time he worked out an elaborate scheme for the invasion of Germany on the coast, not 100 miles from Berlin. No fewer than 600 vessels of all types were ordered for this purpose, but the Dardanelles expedition caused the diversion of forces intended for this service, and the Baltic project was abandoned on the resignation of Lord Fisher, which took place in May, 1915. His last public service was to organise the Board of Inventions and Research, of which he became chairman.

Seldom has Britain been favoured with a man of such single-hearted devotion and of such dynamic force. His loss is irreparable, but he lived to see the triumphant conclusion of his labours in the surrender of the German Fleet, and the successful issue of the war.

Lord Fisher was elected an Honorary Member of the Institution in 1914.

Members.

Thomas Morison Broom was born in Glasgow on 11th July, 1858, and was educated at Greenock, where also he served his apprenticeship. His apprenticeship over, he spent nine years at sea, voyaging to South America, China, Japan, and New Guinea, and gained his chief engineer's certificate in 1886. Three years later he started in business as a consulting engineer in Glasgow, and acted as superintendent engineer to Messrs. Whimster and Watson until 1895, in which year he was appointed engineer superintendent to Messrs. Thomas Dunlop & Sons, Glasgow, and this position he held until 4th October, 1919. Mr. Broom was a member of the Board of Trade Commission on Boiler Explosions, and was for some years engineer surveyor to the Austrian Veritas. In his capacity as consulting engineer he designed and superintended the construction of the sewage steamers "Dalmuir" and "Shieldhall" for the Glasgow Corporation. He died at Crosshill, Glasgow, on 4th October, 1919.

Mr. Broom joined the Institution as a Member in 1893.

Peter Nisbet Cunningham was born at Coatbridge on 3rd September, 1853, and received his early education at the Free Church School, Coatbridge. Later, he studied under Dr. Ross at Gartsherrie Academy. After serving his apprenticeship as an engineer with Messrs. Dick & Stevenson, of Airdrie, he occupied an important position with Messrs. Miller & Co., Vulcan Iron Works.

He was intimately associated with the steel industry almost throughout his career, and was the pioneer of the successful introduction and development in this country of the basic

open-hearth steel process. He acted as manager of the Blochairn Works of the Steel Company of Scotland for many years, and afterwards proceeded to the United States to study the process of manufacture there. While on the other side of the Atlantic, Mr. Cunningham superintended the laying down and starting of the plant of the Middlesborough Iron and Steel Works in Kentucky. On returning to this country he was appointed general manager of Messrs. Stewarts & Lloyds' Clydesdale Steel Works at Mossend, where he remained for over 24 years.

Mr. Cunningham, who had been in failing health for some time, died at Uddingston on 17th August, 1920. He was a prominent figure, and to a forceful personality he added a largeness of heart and depth of feeling which found an outlet in any movement for the amelioration of the workers. He took a keen interest in the welfare of children, and, among many other duties, he was a trustee of the Airdrie Savings Bank. He was a past president of the West of Scotland Iron and Steel Institute and a member of the Committee on Chemistry and Metallurgy of the Royal Technical College, Glasgow. He served on the Council of the Institution from 1911-1919, and during the last five years of that period was a Vice-President.

Mr. Cunningham joined the Institution as a Member in 1884.

Raphael Chrysostomo D'Oliveira was born at Rio de Janeiro in 1869, and received his early education at the Pedro II School there. He came to this country at the age of 18 to continue his technical education, and he gained practical experience in the works of Messrs Yates & Thom, Bolton, and in those of the late firm of Messrs. Aitken, McNeil & Co., Govan. Subsequently he went to France and gained additional experience in the works of the principal sugar-machinery engineers there.

Returning to Brazil, he joined the firm of R. Chrysostomo y

Irmao, and became interested in a number of sugar-cane factories in the Campos district. He took a leading part in the development of the sugar-cane industry in South Brazil, and identified himself with most of the important schemes in that country. During a period of 20 years he was responsible for increasing the production of sugar in the Campos district from 150,000 bags to 1,300,000 bags of a much superior quality. He died at Rio de Janeiro on 1st December, 1919.

Mr. D'Oliveira joined the Institution as a Member in 1900.

John Whitehead Wilson Drysdale was born at Helensburgh in 1849. He was educated at Larchfield Academy in the neighbourhood, and in due time was apprenticed to Messrs. A. & P. Steven, hydraulic engineers, Glasgow. During his apprenticeship and following upon it he studied engineering science under Prof. Macquorn Rankine at Glasgow University. At the age of 25 Mr. Drysdale, in conjunction with a fellow-student, Mr. L. J. Pirie, acquired a small works in London Road, Glasgow, to which the name "Bon Accord," the civic motto of Aberdeen, had been given by the owners, two natives of the northern city. Mr. Pirie's death in 1876 left Mr. Drysdale sole partner of the concern.

While, from the first, centrifugal pumps formed the outstanding speciality, many other varieties of hydraulic machinery were produced. With the development of business, extensions to the premises were made from time to time, but in 1908 it was found necessary to make arrangements for the establishment of new works on a site where expansion was possible and easy. The works at Yoker were laid down and equipped with the most modern machine tools and labour-saving plant, and have since undergone large extensions. During the war period a large amount of work was carried out for the Government, including pumping plant for all kinds of vessels.

After a strenuous business career of 45 years Mr. Drysdale,

owing to failing health, retired from active association with business in 1919. His death occurred at Glasgow on 21st June, 1920.

Mr. Drysdale joined the Institution as a Member in 1884.

Andrew Fisher was born at Paisley on 1st December, 1843, and was educated at the John Neilson Institution. After receiving a practical training under his father, he started for himself, and carried on a successful marine engineering business from 1868 till the time of his death, which took place at Paisley on 19th March, 1920.

Apart from his professional career, Mr. Fisher took a deep and active interest in all that concerned his native town. He was a member of the Town Council for a period of 29 years, and during that time he was raised to the magistracy on eight occasions. He was associated with the electricity department from its inception, and was convener for a number of years. He was a Justice of the Peace for the County of Renfrew.

Mr. Fisher joined the Institution as a Member in 1898.

Ebenezer Hall-Brown was born at Greenock on 9th April, 1862, and was educated at St. Paul's Balfour School and Anderson's College, Glasgow. His practical training began in the works of the Fairfield Shipbuilidng and Engineering Co. Ltd., Govan. On the completion of his apprenticeship he remained with the firm for three years, during which time he was specially engaged upon the design and construction of valve gears for marine steam engines. From Fairfield he went to Messrs. T. Richardson & Sons, Hartlepool, where for several years he was head of the scientific department, and chiefly responsible for the designs of all the machinery produced by that firm. Under his supervision there were prepared the

designs for the first triple-expansion engine constructed in Britain for water-works purposes.

In 1892 he resigned his position with Messrs. Richardson, and returning to the Clyde he entered into partnership with Mr. John A. Buttery, and took over the St. Helen's Engine Works, Helen Street, Govan, previously occupied by Mr. William Kemp. Here, under the name of Hall-Brown, Buttery & Co. the firm developed the business and undertook the design and construction of marine engines. Ultimately the shipbuilding firm of Messrs A. Rodger & Co., Port-Glasgow, in conjunction with Mr. Hall-Brown, took over the St. Helen's Engine Works, Mr. Hall-Brown continuing to be the general manager. Over a period of about 20 years, up till 1911-12, about 150 sets of marine engines were constructed and installed, in addition to which many special items were produced, such as gas producers, and gas engines to the designs of Prof. Rowden, Mr. Hall-Brown's old teacher in Anderson's College.

In 1912 Mr. Hall-Brown accepted the appointment of general manager of the Middlesbrough Works of Messrs. Richardsons, Westgarth & Co. Ltd. Under his supervision there, besides the firm's main output of standard marine steam engines for high-class cargo ships, there were undertaken the manufacture of rolling-mill engines, steel-works plant, and gas engines, while the first sea-going motor ship, "Eavestone," was equipped with a Carels-Diesel engine.

Mr. Hall-Brown all along evinced a keen interest in the scientific as well as the practical side of engineering, and he engaged in research and experimental work in various directions. He closely identified himself with the Institution, and took a keen interest in the students' section, and spared no effort in promoting in every way its development and usefulness. The ordinary proceedings of the Institution were frequently enlivened and enriched by his contributions to discussions. He died suddenly of heart failure on 13th May, 1920

Mr. Hall-Brown joined the Institution as a Graduate in 1883,

and became a Member in 1895. He served at various times on the Council, both as a Councillor and Vice-President, and was President for sessions 1911-13.

John Lockie was born in Glasgow on 2nd February, 1853, and received his education at the Glasgow Training College and the West of Scotland Technical College. His engineering apprenticeship was served in the works of Messrs. Norman & Co., and to gain experience he went to sea for nearly 12 months. By dint of study he gained a Whitworth Scholarship, and was appointed, in the intervals of the Glasgow University course, experimenting officer in the Industrial Museum, Edinburgh. For some time he served as an assistant to Lord Kelvin, and subsequently as an assistant to Prof. Archer at the Edinburgh University.

Thereafter he opened a business as consulting engineer in Leith, and in 1880 started a Nautical Academy for marine engineers. Soon after settling in Leith he was appointed head-master of the Leith Science College, and for 14 years held the position of principal. Relinquishing that appointment, he started "The Steamship," to the development of which he energetically devoted himself. He also carried on his engineering academy with the help of assistants until shortly before his death, which took place at Leith on 26th December, 1919.

Mr. Lockie joined the Institution as a Member in 1897.

Hector Maccoll, principal of the firm of Maccoll & Co., Ltd., marine engineers, boiler makers, and shipwrights, Belfast, passed away on 22nd April, 1920, after a brief illness, in his 78th year.

Mr. Maccoll was a native of Glasgow, and spent his early days with Messrs. J. Jack & Co., engineers and boilermakers,

Bootle, who at one time engined many ships for Messrs. Harland & Wolff, Ltd. He went to Belfast in the 'eighties, and eventually became one of the principals of Messrs. McIlwaine & Maccoll, shipbuilders, whose yard now belongs to Messrs. Workman, Clark & Co., Ltd. His firm gave up the shipbuilding business in 1894 after constructing some sixty steamers of moderate tonnage, and ever since that time Mr. Maccoll devoted himself to the engineering repairing business, which he carried on with success.

Mr. Maccoll joined the Institution as a Member in 1874.

Kenneth Mackenzie was born at Glasgow on 9th August, 1882, and when very young his parents removed to Liverpool. He was educated at the Bedford Road Board School, the Liverpool Institute, and finally, by virtue of his ability, he passed to the High School. On leaving school he elected to take up engineering as a profession, and served his apprenticeship with Messrs. David Rollo & Sons, for which firm his father was manager, later completing his studies at the Liverpool University, graduating as Master of Engineering. He afterwards became one of the drawing-office staff of Messrs. John Brown & Co., Clydebank, and remained there for a period of six years. Returning to Liverpool, he took over the position of engineer draughtsman with Messrs. David Rollo & Sons, and subsequently succeeded to the post of chief draughtsman of the Cunard Company. About the beginning of 1915 he obtained the appointment of chief superintendent engineer to the Canadian Pacific Ocean Services, Ltd., and held this position up to the time of his death, which took place suddenly at his residence in Bootle on 9th February, 1920.

Mr. Mackenzie was a highly respected member of the Liverpool Superintendent Engineers' Committee, and had been elected chairman for the year 1920. The engineering community by his death, has suffered a serious loss, and it is

indeed a tragedy that a brilliant life so full of promise should be cut off in its youth.

Mr. Mackenzie joined the Institution as a Student in 1906, and became a Member in 1916.

Alfred Marriott was born at Glasgow on 18th April, 1868, and educated at St. Peter's School, York. He served his apprenticeship with Messrs. Marriott & Graham, boiler-makers, Govan, of which firm his father was a director. Mr. Marriott spent the whole of his business career in the service of the firm, and on the death of his father assumed control. He died at a nursing home in Glasgow on 23rd March, 1920.

Mr. Marriott joined the Institution as a Member in 1904.

Thomas Morton died at his residence at Partick on 11th August, 1920, in his 77th year. A native of Catrine, Ayrshire, Mr. Morton entered the service of Messrs. Barclay, Curle & Co., Ltd., Glasgow, as a youth, and was associated with the firm for the long period of 58 years. He had charge of the repairing branch of the business for many years, and in 1901 he was made a director. During the last 10 years he was at the head office, and acted as director and cashier.

Mr. Morton was an amateur water colour painter of some distinction, and spent all his spare time in the pursuit of his hobby. He interested himself very much in the welfare of the workers, and was well known and highly respected in Clyde shipbuilding circles.

Mr. Morton joined the Institution as a Member in 1907.

John Steel Nicholson was born at Alford, Aberdeenshire, on 21st December, 1879, and received his early education at

Alford, and Gordon's College, Aberdeen. Subsequently he removed to Glasgow, where, after an excellent record at the Glasgow and West of Scotland Technical College, he became a student in the engineering classes at the Glasgow University in 1898. He had a distinguished University career, graduating B.Sc. in 1899 and gaining many prizes, including the first "Walker" prize, and the "George Harvey" prize (divided). In the summer of 1896 Mr. Nicholson commenced his practical work in engineering with Messrs. M. Paul & Co., Ltd., Dumbarton, and continued his apprenticeship there until 1901. From 1901 to 1904 he was demonstrator in the newly opened James Watt laboratories, under Prof. Barr, and during that time he also taught evening science classes in Dumbarton Academy and Coatbridge Technical School and Mining College. In 1903 he gained first place in the annual Whitworth Scholarship Examinations. After a year's special study in Germany he was, in 1905, appointed by the University Court of Glasgow University chief laboratory assistant to the professor of engineering and lecturer in electrical engineering. While at the University he collaborated with Dr. J. B. Henderson in carrying out research work on Armature Reaction in Alternators, and in conjunction with Prof. A. Barr, on the Influence of Temperature, Loading, etc., in the Elastic Limit and Breaking Stress of Mild Steel.

In 1915 he joined the Department of Aero Supplies, and became a Section Director of the Supply Department with the rank of Major, subsequently transferring to the Technical Department of the Air Ministry. On demobilisation he returned to his former duties at the University, and was awarded, in 1920, the degree of D.Sc. (Eng.). In January of this year he contributed a paper to the Institution on "The Development of Metal Construction in Aircraft."

Possessing excellent abilities, a wide and sound knowledge, untiring energy and devotion to duty, and a genial disposition, Mr. Nicholson commanded the respect and esteem of all with

whom he came into contact. He died at Glasgow on 22nd July, 1920.

Mr. Nicholson joined the Institution as a Member in 1910.

Thomas Cairncross Nicholson was born at South Shields on 8th August, 1874, and after attending the High School there he was apprenticed at the age of sixteen to marine engineering with the Wallsend Slipway and Engineering Co., Ltd. After three years' practical work in the shops, he entered the drawing office, where he served three years as a draughtsman. In 1896 he joined an oil-tank steamer as fourth engineer, and for about six years thereafter served in ocean-going merchant steamers belonging to various British concerns, and qualified himself in the several grades.

In 1901 Mr. Nicholson received an appointment as outside foreman engineer with Messrs. Mordey, Carney & Co., Southampton. When that concern was taken over in 1904 by the well-known firm of Messrs. John I. Thornycroft & Co., he was promoted assistant manager. In 1909 he joined the service of the Clyde Shipping Co. as assistant to Mr. David C. Hamilton, and succeeded to the position of marine superintendent of the company on Mr. Hamilton's death in September, 1912. For a considerable time prior to his death Mr. Nicholson had been in failing health—lung and throat trouble in the winter months especially being the cause. He gradually grew worse, and passed away on 8th January, 1920.

Mr. Nicholson joined the Institution as a Member in 1912.

Richard Ramage, one of the founders of Messrs. Ramage & Ferguson Ltd., Leith, passed away at The Hawthorns, Leith, on 16th July, 1920. He was born at Temple, Midlothian, on the 25th June, 1834, and, indentured in 1851, received his early

training in shipbuilding with the firm of Messrs. Barclay, Curle & Co. Ltd., Glasgow. After gaining experience in the iron and steel construction of ships, he was appointed general manager to Messrs. William Denny & Bros., shipbuilders, Dumbarton, in 1870. Seven years later he joined with Mr. Ferguson, whose father was a partner in the Barclay, Curle firm, in establishing the shipyard at West Pier, Leith, which is still carried on under the name of Ramage & Ferguson, Ltd. For many years this firm held a premier position in Leith shipbuilding. Although cargo and passenger steamers formed the larger part of the output, the firm specialised in steam yacht construction, many yachts being of composite construction, built for both home and foreign owners. Since 1880 the firm have supplied both engines and boilers to the vessels they constructed.

About five or six years ago he disposed of his interest in the firm, and since then Mr. Ramage lived in comparative retirement. For a number of years he took an active interest in public affairs, and was for a time a member of Leith Dock Commission, the Town Council, and School Board. He was also a Justice of the Peace for the County of Midlothian.

Mr. Ramage joined the Institution as a Member in 1873.

George Caldwell Thomson was born at Torquay on 5th July, 1860, and was educated at the Glasgow Academy and Glasgow University. His apprenticeship was served partly at Woehrmann's Shipbuilding and Engineering Works, Riga, and partly with Messrs. John McDowall & Sons, Johnstone. After gaining experience as a sea-going engineer, he again entered Woehrmann's works, and left at the end of two years to take up the duties of assistant manager in the engineering works of Richard Pohle in the same town. In the latter capacity he remained for 16 years, and then accepted an appointment as assistant manager of the Riga branch of Messrs. Thomas Firth

& Sons, Sheffield, and became manager just before the compulsory removal of the works to Samara. Having settled the firm's business there, he returned to Scotland. He died at Edinburgh on 27th April, 1920.

Mr. Thomson joined the Institution as a Member in 1893.

Ebenezer Kennedy Wallace died at Dumbreck, Glasgow, on 15th June, 1920, in his 76th year. He was a native of Leith, and served his apprenticeship to marine engineering with Messrs. Palmers Shipbuilding and Iron Co. Ltd., Jarrow-on-Tyne, and Messrs. A. & J. Inglis Ltd., Glasgow.

In 1866, when 21 years of age, he went to sea as third engineer in the paddle steamer "Ville de Salto," and for several years served with various shipping companies, ultimately becoming a chief engineer. In 1890 he finally left the sea and began business as a superintendent engineer. He took charge of the steamers owned and managed by Messrs. J. & A. Wyllie, Troon, of which concern his brother, Mr. Peter Wallace, was one of the founders. In 1900 Mr. Wallace started a consultant and superintendent business in St. Enoch Square, Glasgow, and from that time onwards many new steamers of from 5,000 to 8,500 tons were built to the specifications and under the superintendence of Messrs. Wallace & Son.

Mr. Wallace joined the Institution as a Member in 1909.

James Weir was born at Blackburn, Linlithgowshire, in 1839. His father died in 1845, and shortly afterwards the family removed to Glasgow. Having a natural bent towards engineering, Mr. Weir, in 1860, became an apprentice with the firm of Messrs. Randolph & Elder, Glasgow. His apprenticeship over, he, with a view to getting a better knowledge of the practical working of marine engines, went to sea, and served in various

grades up to chief engineer. The necessity for improving the conditions under which boilers were worked so appealed to him that he began inventing and patenting appliances having this object, defined in the patent specification as " the prevention of corrosion in boilers." In 1870 he commenced business in Liverpool as a consulting engineer, but eight years later removed to Glasgow, where he was joined by his brother George, and the firm became G. & J. Weir. Mr. Weir devoted his time and talents to the development of his inventions and the patenting of new apparatus for improved working of both boilers and engines. The first of the series was the hydrokineter, which was taken up rapidly, and it was followed by the conserver, the feed heater, the separate feed pump, the Weir condenser, and the independent air pump.

With the expansion of business the brothers Weir sought more adequate premises than their first office in Jamaica Street, and in 1885 laid down Holm Foundry at Cathcart, which at first employed about a hundred men, but has since so developed that the works now cover an area of 17 acres and employ about 3,000 workers. Shortly after the establishment of the new works, the necessity for the use of fresh water for feed make-up purposes in high-pressure boilers was recognised by Mr. Weir, and he was the first to place on the market an evaporator for the mercantile marine. Its advantages were recognised by the Admiralty, and it was adopted by the Navy and fitted to a large number of warships. The original evaporators were fitted in conjunction with Normandy distilling condensers, but later the Weir condenser was developed, and now Messrs. G & J. Weir furnish complete distilling plants for naval purposes.

Mr. Weir spent considerable time in the investigation of water-tube boiler problems, and at the summer meeting of the Institution at Sheffield, in 1899, he read a paper on " The Problem of Combustion in Water-Tube Boilers, and a Means of its Solution." His excursions into the domain of physical

science have borne fruit in two small volumes, "Terrestrial Energy" and "Steam Engine Efficiency," both distinguished by a characteristic originality of view and disregard of accepted traditions. In 1910 Mr. Weir withdrew from active participation in his firm's business, and took up residence at his country estate of Over Courance, Dumfriesshire, where he interested himself in agricultural pursuits until his death, which took place on 10th July, 1920. His career forms a striking example of one who, by sheer force of natural endowments and earnestness of purpose, rose to the very pinnacle of engineering prominence.

Mr. Weir joined the Institution as a Member in 1874. Altogether he served 14 years on the Council, during five of which he was a Vice-President, retiring in 1910.

Associate Members.

GEORGE ERNEST LAIRD was born at Edinburgh on 23rd April, 1890, and educated at Edinburgh Academy and Pembroke College, Cambridge. He left the latter in 1911, after obtaining the B.A. degree, and started as an apprentice with Messrs. Scotts' Shipbuilding and Engineering Co. Ltd., Greenock. He remained with that firm in various capacities till December, 1918, when he was compelled to resign on account of ill health His death took place at Edinburgh on 14th March, 1920.

Mr. Laird joined the Institution as an Associate Member in 1916.

JAMES SMITH was born at Glasgow on 30th July, 1869, and was educated at St. Matthew's Sessional School and the Andersonian College, Glasgow. He served his apprenticeship in the workshops and drawing office of Messrs. Lees, Anderson & Co., and for some years afterwards was employed in the drawing office of Messrs. Barclay, Curle & Co. Leaving that

firm he joined the drawing office staff of the Fairfield Shipbuilding and Engineering Co. Ltd., Govan, with whom he remained for about 20 years, when he was compelled to resign his position on account of ill health. For the last two years of his life he was engaged as a leading draughtsman with Messrs. Babcock & Wilcox Ltd., Renfrew, and was instrumental in forming a class for young engineers which met on Saturday forenoons within the works. The class was not intended to compete in any sense with ordinary engineering classes, but was started with a view to training young engineers on the side of self-development, and the results obtained during the 18 months the class was in operation were most promising, and showed what could be done by the application of ordinary common-sense methods in developing the thinking faculties of boys who possessed only a very elementary education. Mr. Smith died at a nursing home in Glasgow on 26th January, 1920.

Mr. Smith joined the Institution as a Graduate in 1892, and became an Associate Member in 1903.

Associates.

William Begg was born at Glasgow on 2nd April, 1854, and received his education at the Glasgow Academy. After completing his apprenticeship with Messrs. A. & P. Steven, Provanside Engine Works, Glasgow, he spent some time on the staff of Messrs. The Tharsis Sulphur and Copper Co. Ltd. In 1877 he went into partnership with his father, who that year had acquired the wire-weaving business of Messrs. William Riddell & Co. Mr. Begg was the inventor of several improvements in wire-weaving machinery, and was actively interested in this industry at the time of his death, which took place suddenly at Coulter, Lanarkshire, on 4th October, 1919.

He was a keen volunteer, and served for nearly 30 years in

the 1st Lanarkshire Volunteers, retiring with the honorary rank of Major.

Mr. Begg joined the Institution as an Associate in 1886.

Thomas W. McIntyre was born in 1860, and was educated at Glasgow Academy and Merchiston Castle School. He began in 1885 his business career with Mr. Joseph Maclay (now Sir Joseph Maclay, Shipping Controller) as shipbroker and shipowner under the name of Maclay & McIntyre. The business proved a very prosperous one, and the firm at one time owned a very large number of cargo-carrying steamers. Mr. McIntyre retired from shipping affairs about 15 years ago, and latterly devoted himself chiefly to the management of his estate at Sorn, Ayrshire.

Before his retirement he was, for a time, chairman of the Glasgow Committee of Lloyd's Register, a director of the Laird Line of steamships, and from 1896 to 1906 he was a director of the Clyde Steamship Owners' Association, of which he was chairman in 1902-3. He was president in 1906 of the Glasgow Shipowners' and Shipbrokers' Benevolent Association. Mr. McIntyre was also connected with various commercial concerns, and was a director of the Glasgow and South Western Railway Company. He died at Sorn Castle, Ayrshire, on 20th September, 1920.

Mr. McIntyre joined the Institution as an Associate in 1893.

Frederick Lear Wrede was born at Greenock on 5th May, 1850, and was educated there at Dr. Buchanan's Academy and Greenock Academy. Leaving school, he joined the office of Messrs. James Little & Co., Greenock, about 1866, removing to Glasgow when the head office of the firm was transferred there about 1875. He subsequently became a partner in the

firm, and after it was registered as a limited company he acted as managing director, retiring at the end of 1919, having had a continuous connection with the business for about 53 years. He died at Greenock on 12th September, 1920.

Mr. Wrede was a director of the Clyde Steamship Insurance Association Ltd. from 1903 to 1918, and was chairman from 1914 to 1918. He was also a director of the Clyde Steamship Owners' Association from 1908 to 1918.

He joined the Institution as an Associate in 1898.

INDEX.

	PAGE
A New Type of Shipyard Crane—by W. Hök	266
Introduction	266
Description	269
Dimensions and Capabilities	273
Weights and Cost	276
Reflections	276
Adding Machines	138
Address by President	1
Aircraft	26
Aircraft Construction, Secondary Failures in	190
Aircraft Construction, Steel *v.* Duralumin in	193
Aircraft Metal Wings	231
Aircraft Spars, Shear Deflection in	209
Alcohol as a Fuel	23
Aluminium Alloys	19
Annual Report of Council	367
Annual Subscriptions, Increase of	361
Arithmetical Machines	128
Arithmometers	130
Articles of Association	xi
Balance Sheet	374
Begg, William, Memoir of	440
Board of Trade Consultative Committee	385
Books added to the Library by Purchase	377
British Corporation Technical Committee	386
British Marine Engineering Design and Construction Committee	387
Broom, Thomas Morison, Memoir of	426
Bye-Laws	xxix
Calculating Machines—by Dr. E. M. Horsburgh	117
Historical Sketch	117
Modern Arithmetical Machines	128
Arithmometers	130

PAGE
The Brunsviga Group - - - - - - - - - - 135
The Adding Machines - - - - - - - - - - 138
The Millionaire - - - - - - - - - - - 145
Machines in which the Division Operation is Automatic - - 150
Tabulating and Sorting Machines - - - - - - - 158
The Utility of the Calculating Machines - - - - - 160
Carbon Steel - - - - - - - - - - - - 239
Conjoint Board of Scientific Societies - - - - - - - 387
Construction of Highways - - - - - - - - - 20
Contents - - - - - - - - - - - - - vii
Corrosion of Steel Strip - - - - - - - - - 242
Council Report - - - - - - - - - - - 367
Crane, Shipyard, Dimensions of - - - - - - - - 273
Crane, Shipyard, Weights and Cost of - - - - - - 276
Cruiser Stern, Advantages of - - - - - - - - 96
Cruiser Stern, Types of - - - - - - - - - 101
Cunningham, Peter Nisbet, Memoir of - - - - - - - 426

Daimler Engine - - - - - - - - - - - - 5
Deceased Members - - - - - - - - - - - 423
Design, Treatment, and Handling of the Snaps, etc., used in Pneumatic Hammers—by G. Denzil Hollis - - - - - - 163
Nomenclature - - - - - - - - - - - 163
Standards - - - - - - - - - - - - 164
Design - - - - - - - - - - - - - 165
Material and Heat Treatment - - - - - - - 168
Handling in use - - - - - - - - - - - 171
Destroyer, Distribution of Weights in - - - - - - - 315
Destroyers, Speed of - - - - - - - - - - - 318
Destroyers, Strength of - - - - - - - - - - 322
Discussion on "Photo-Elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members" - - - - - - - - - - - - 78
Discussion on "The Cruiser Stern" - - - - - - - - 106
Discussion on "Design, Treatment, and Handling of the Snaps, etc., used in Pneumatic Hammers" - - - - - - - - - 173
Discussion on "The Development of Metal Construction in Aircraft" 243
Discussion on "A New Type of Shipyard Crane" - - - - - 277
Discussion on "Experiments on Riveted Joints" - - - - - 298
Discussion on "High-Speed Craft During the War" - - - - - 326
D'Oliveira, Raphael Chrysostomo, Memoir of - - - - - - 427

PAGE
Drysdale, John Whitehead Wilson, Memoir of - - - - - - 428
Duralumin Spars, Tests on - - - - - - - - - - 225
Duralumin Strip - - - - - - - - - - - - 241
Duralumin Wings for Aircraft - - - - - - - - - 234

Engineering Standards Association: Sectional Committee on Machine Parts - - - - - - - - - - - - - 388
Engineering Training, Report of Committee on - - - - - 392
Experiments on Riveted Joints—by Dr. James Montgomerie - - 284
Methods of Failure in Riveted Joints - - - - - - 285
Specimen Joints - - - - - - - - - - - 287
Treble-Riveted Joints—"Slip" - - - - - - - - 288
Quadruple-Riveted Joints—"Slip" - - - - - - - 291
Elastic Qualities of Joints - - - - - - - - - 294
Results of Experiments - - - - - - - - - 297

Failures in Aircraft Construction - - - - - - - - 190
Fisher, Andrew, Memoir of - - - - - - - - - 429
Fisher, Lord, Memoir of - - - - - - - - - - 423
Flight Tests - - - - - - - - - - - - 235

Glasgow and West of Scotland Commercial College - - - - 383
Glasgow School of Art - - - - - - - - - - 383
Gunboats - - - - - - - - - - - - - 324

Hall-Brown, Ebenezer, Memoir of - - - - - - - - 429
Handling of Snaps - - - - - - - - - - - 171
High-Speed Craft During the War—by W. W. Marriner - - - 313
Coastal Motor-Boats - - - - - - - - - - 314
Distribution of Weights in a Modern Destroyer - - - - 315
Under-Water Form of Hull - - - - - - - - - 316
Advantages of Superheating - - - - - - - - 319
Strength of Destroyers - - - - - - - - - - 322
China Gunboats - - - - - - - - - - - 324

Index - - - - - - - - - - - - - - 443
Internal Combustion Engines - - - - - - - - - 27

"James Watt" Anniversary Dinner - - - - - - - - 342

Laird, George Ernest, Memoir of - - - - - - - - 439
Libraries, etc., which receive the Institutions Proceedings - - - 378
Library, Books Added to by Purchase - - - - - - - 377
Library Committee, Report of - - - - - - - - - 376

PAGE
Library, Donations to - - - - - - - - - - - - 376
Library, Periodicals Received at - - - - - - - - 380
Lloyd's Technical Committee - - - - - - - - - 390
Lockie, John, Memoir of - - - - - - - - - - 431

Maccoll, Hector, Memoir of - - - - - - - - - 431
McIntyre, Thomas W., Memoir of - - - - - - - - 441
Machine-Tool Practice - - - - - - - - - - 28
Mackenzie, Kenneth, Memoir of - - - - - - - - 432
Main-Plane Spar Design for Aircraft - - - - - - - 229
Marriott, Alfred, Memoir of - - - - - - - - 433
Material and Heat Treatment of Snaps - - - - - - 168
Members Deceased - - - - - - - - - - 423
Memorandum and Articles of Association - - - - - - ix
Metal Ailerons for Aircraft - - - - - - - - - 231
Metal Construction in Aircraft - - - - - - - - 186
Metal Ribs for Aircraft - - - - - - - - - 231
Metal Wings for Aircraft - - - - - - - - - 231
Millionaire Adding Machine - - - - - - - - 145
Minutes of Proceedings - - - - - - - - - 349
Morton, Thomas, Memoir of - - - - - - - - 433
Motor-Boats, Coastal - - - - - - - - - - 314
Motor-Car Engines - - - - - - - - - - 7
Motor Vehicles, Speed of - - - - - - - - - 13

Nicholson, John Steel, Memoir of - - - - - - - - 433
Nicholson, Thomas Cairncross, Memoir of - - - - - - 435

Obituary - - - - - - - - - - - - 423
Office-Bearers - - - - - - - - - - - - iii
Office-Bearers, Election of - - - - - - - - - - 365

Photo-Elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members—by Prof. E. G. Coker, M.A., D.Sc., F.R.S., K. C. Chakko, M.Sc., and Y. Satake - - - - - - - - - - - 34
Experimental Determinations of Stress Distribution Around a Hole 35
Range of Stress Variation - - - - - - - - - 46
Isoclinic Lines - - - - - - - - - - - 58
Comparison of Stress Distribution in Perforated Steel and Nitro-Cellulose Tension Members - - - - - - - - 61
Physical Properties of Steel - - - - - - - - - 15

PAGE
Plain Carbon Steels - - - - - - - - - - - 239
Presidential Address - - - - - - - - - - - 1
Presidents of the Institution - - - - - - - - - v
Proceedings, Minutes of - - - - - - - - - - 349

Quadruple-Riveted Joints - - - - - - - - - - 291

Ramage, Richard, Memoir of - - - - - - - - - 435
Report of Committee on Engineering Training - - - - - 392
Report of Council - - - - - - - - - - - 367
Report of Library Committee - - - - - - - - - 376
Reports of Institution's Representatives on Various Boards - - 382
Representatives of the Institution - - - - - - - - iv
Riveted Joints, Failure of - - - - - - - - - - 285
Roll of the Institution - - - - - - - - - - 367
Royal Technical College - - - - - - - - - - 384
Secondary Failures in Aircraft Construction - - - - - 190
Shear Deflection in Aircraft Spars - - - - - - - - 209
Ship Electrical Equipment Committee - - - - - - 390
Smith, James, Memoir of - - - - - - - - - - 439
Snaps, Design of - - - - - - - - - - - - 165
Static Tests on Steel Wings for Aircraft - - - - - - 232
Steel, Carbon - - - - - - - - - - - - 239
Steel, Physical Properties of - - - - - - - - - 15
Steel Strip for Aircraft - - - - - - - - - - 235
Steel *v.* Duralumin in Aircraft Construction - - - - - 193
Strength of Destroyers - - - - - - - - - - 322
Stress Distribution in Perforated Steel - - - - - - 61
Stress-Load Characteristics for Duralumin Spars - - - - 217
Stress-Load Characteristics for Steel Spars - - - - - - 214
Superheating, Advantages of - - - - - - - - - 319

Tabulating and Sorting Machines - - - - - - - - 158
Tests on Duralumin Spars - - - - - - - - - - 225
The Cruiser Stern—by P. A. Hillhouse, B.Sc. - - - - - - 95
Advantages of a Cruiser Stern - - - - - - - - 96
Types of Cruiser Stern - - - - - - - - - 101
Comparative Cross Sections in Wake of Propellers - - - 103
The Development of Metal Construction in Aircraft—by Major J. S. Nicholson, O.B.E. - - - - - - - - - - - 185
Metal Construction - - - - - - - - - - 186

PAGE

Choice of Type of Aeroplane for Purposes of Experiment - - 195
Comparison of the Experimentally Determined Characteristics of the Various Designs, with their Predetermined Characteristics 211
Larger-Sized Main-Plane Spars suitable for the Vimy and Handley-Page Machines - - - - - - - - - - - 221
Further Series of Handley-Page Spar Specimens in Duralumin - 225
Main-Plane Spar Design: General Conclusions - - - - - 229
Metal Ribs, Ailerons, and Wings - - - - - - - - - 231
Materials of Construction for Main-Plane Spars, Ribs, etc. - - 235
Thomson, George Caldwell, Memoir of - - - - - - - - 436
Treasurer's Statement - - - - - - - - - - - 372
Treble-Riveted Joints - - - - - - - - - - - 288

Wallace, Ebenezer Kennedy, Memoir of - - - - - - - 437
Weir, James, Memoir of - - - - - - - - - - 437
William Froude National Tank - - - - - - - - - 383
Wings, Metal, for Aircraft - - - - - - - - - - 231
Wrede, Frederick Lear, Memoir of - - - - - - - - 441

Index of Authors.

PAGE

Adam, J. L., Discussion - - - - - - - - - - 83
Anderson, James, Discussion - - - - - - 332, 336, 337
Anderson, John, Discussion - - - - - - - - - 111
Baker, G. S., O.B.E., Discussion - - - - - - - - 110
Burnside, William, Discussion - - - - - - - - 177
Chakko, K. C., M.Sc., Paper 34, Discussion - - - - - 87
Coker, Prof. E. G., M.A., D.Sc., F.R.S., Paper 34, Discussion - 87
Dennistoun, A. B., Discussion - - - - - - - - 243
Duncan, Bernard A., Discussion - - - - - - - 257
Duncan, W. O., Discussion - - - - - - - - 246
Edgar, G. R., B.Sc., Discussion - - - - - - - 308
Elvidge, Gordon, Discussion - - - - - - - - 248
Hamilton, Andrew, Discussion - - - - - - - - 108
Hayward, T. A., Discussion - - - - - - - 302, 336
Hillhouse, P. A., B.Sc., Paper 95, Discussion - - - - - 113
Hök, W., Paper 266, Discussion - - - - - - - 281
Hollis, G. Denzil, Paper 163, Discussion - - - - - - 179
Horsburgh, Dr. E. M., Paper - - - - - - - - 117
Hunter, Norman M., Discussion - - - - - - - 326
Huntley, J. H., Discussion - - - - - - - - 280
McCance, Dr. Andrew, Discussion - - - - - - - 80
McLaren, R. A., O.B.E., Discussion - - - - - - 174, 280
McLean, David S., Discussion - - - - - - - - 245
Marriner, W. W., Paper 313, Discussion - - - - - - 339
Montgomerie, Dr. James, Paper 284, Discussion - - - - 309
Murray, Dr. T. Blackwood, Presidential Address 1, Discussion
78, 173, 298, 336
Myles, David, Discussion - - - - - - - - - 175
Nicholson, Major J. S., O.B.E., Paper 185, Discussion - - - 258
Nicol, George, Discussion - - - - - - - - - 301
Parker, Edward H., Discussion - - - - - - - 113, 328
Pratt, H. B., Discussion - - - - - - - - - 249
Richardson, James, B.Sc., Discussion - - - - - 85, 336, 337
Riddlesworth, W. H., M.Sc., M.Eng., Discussion
78, 106, 178, 247, 277, 300, 339

PAGE
Satake, Y., Paper 34, Discussion - - - - - - - - 87
Taylor, John F., Discussion - - - - - - - - 176
Thomson, William, B.Sc., Discussion - - - - - - - 306
Watson, William S., Discussion - - - - - - - - 329
Weddell, Alexander H., B.Sc., Discussion - - - - - - - 245
Wylie, Major H. N., Discussion - - - - - - - - 251
Yarrow, Harold E., C.B.E., Discussion - - - - - - - 326